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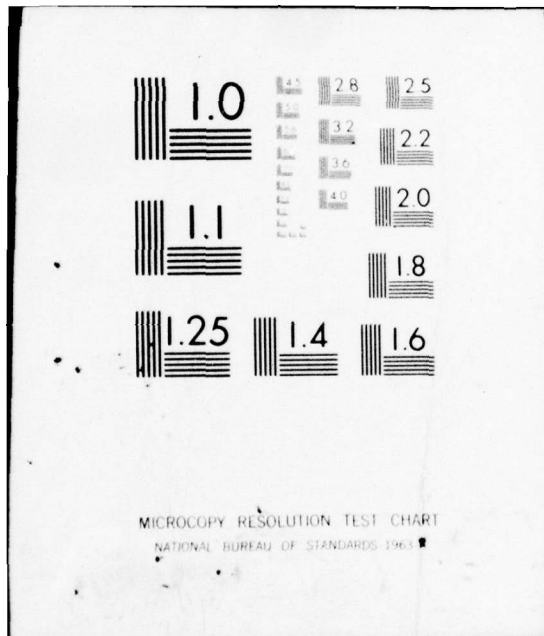
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Armor Development in the Soviet Union and the United States

Arthur J. Alexander



A report prepared for
DIRECTOR OF NET ASSESSMENT,
OFFICE OF THE SECRETARY OF DEFENSE



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This historical, comparative study of armor development in two dissimilar countries traces the constancies of the R&D process through shifting institutions and environments. To develop a deeper understanding of the weapons acquisition process, the author examines several important relationships: (a) the interactions among development, doctrine, perceived threats, and economic and technological capabilities; (b) the dependence of the style of the development process on the rate of technological change and on the choice of what to produce; (c) the effectiveness of alternative R&D strategies. Although product improvement of existing design has been the primary mode of increasing the value of tanks, the more than 50 years of armor development in both countries indicate that two other elements are also essential to an effective R&D strategy: (1) independent development of components and technology; and (2) construction and testing of experimental prototypes. Bibliog. (DGS)
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PREFACE

This report presents a comparative study of tank ("armor") development in the Soviet Union and the United States. A principal goal of the study was to improve the understanding of the weapons acquisition process in these two countries. A secondary, but broader, goal was to learn more generally about the development of technologically advanced systems. Examination of armor development in two dissimilar countries over many years should allow the constancies of the process to be observed through shifting institutions and environments. The lessons learned here may therefore be more robust than if based on narrower grounds.

Development is not treated exhaustively in the report. Rather, the author's aim has been to choose those lines of development and those elements of the environment that best illustrate the main trends and that figure most importantly in final outcomes. The narrative therefore proceeds with many shifts in perspective: in some instances, closing in for details; in others, drawing back for abstraction and generalization. Since development cannot be understood in isolation from its environment, the author also discusses doctrine and organization. These matters are subsidiary to the primary interest of the report, however, and so are treated in less detail than the development process itself. The study is directed to persons concerned with Soviet research and development, military R&D, and armor development, and more broadly to persons interested in how various government organizations have managed the development of technologically advanced systems.

The research reported here was sponsored by the Director of Net Assessment, Office of the Secretary of Defense.

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SUMMARY

A Soviet strategic doctrine that evolved in the 1920s and 1930s was based on the massive use of technologically advanced military weapons against an expected coalition of "aggressive capitalist nations." Although the need for tanks *en masse* was questioned following World War II, it has continued to shape policies affecting tanks.

Soviet tank development can be divided into four distinct phases: (1) the establishment of tank design and production facilities from 1929 to 1931 to meet the demands of strategy; (2) the experimental development and production of new technology and designs in the 1930s, culminating in the T-34; (3) mass production of proven designs during World War II; and (4) product improvement of well-proven designs in the postwar period. The T-62 that first appeared in 1962 can be directly traced to the T-34, and will continue to be one of the principal components of Soviet tank forces into the 1980s.

Like many Soviet weapons, tanks are relatively uncomplicated, with emphasis placed on commonality of subsystems and standardization of parts. Improved weapons are primarily the outcomes of a process of cumulative product improvement and evolutionary growth. The pattern of simplicity, commonality, and incremental change may be in part a successful response to the limitations and constraints of the centrally planned, seller-dominated Soviet economy. At least equally important influences molding the pattern of development are (1) the doctrine of quantity and mass and (2) the relatively low skill levels of the large citizen-army. The success of this approach to weapon development and production during World War II has continued to dominate the Soviet postwar years.

In the United States, tanks were distributed throughout the infantry following World War I, and U.S. military doctrine assigned them the role of aiding infantry in the attack. General MacArthur, as Chief of Staff, called for cavalry to assume the primary role of mechanization in 1930, but did not centralize tanks into any one organization. The cavalry missions, however, gradually became more important as tanks

grew in number and capability. Large-scale maneuvers and the European war in the late 1930s pointed to a modification of doctrine and a demand for more, and more modern, tanks.

Tank R&D budgets during the interwar years were low, averaging about \$60,000 per year. Only 35 tanks were built in the United States from 1920 to 1935, whereas the Soviet Union was producing 3000 per year.

The prototypes built during this period provided experience in the design, construction, and operation of the principal tank components. In 1937, 170 M2A2 light tanks were produced using the subsystems developed earlier. An improved set of the same subsystems was used on a medium-tank design, which evolved into the medium M3 Grant and M4 Sherman.

During World War II, production dominated U.S. tank development as it had in the Soviet Union. More than 48,000 M4 Sherman tanks were produced--a quantity greater than that of any other tank design.

From 1943, design centered on the experimental T20 series of medium tanks. More than 15 configurations were built that tested various combinations of guns, transmissions, and suspensions. The M26 Pershing evolved from this series. Product improvement and evolutionary changes to the M26 produced the M60. Several improved M60 variants will form the bulk of U.S. tank forces well into the 1980s.

In the 1960s, the evolutionary style of tank development was displaced by the "weapons system concept" whereby the tank as a whole and most subsystems were developed simultaneously to high levels of performance that pushed the technological state of the art. These systems were very expensive to develop and produce. Moreover, they became available much later than planned, and their performance levels proved disappointing.

The cost per ton of tanks, when adjusted for inflation, has shown no trend (either up or down) from 1918 to 1960. However, the cost of tanks developed according to the weapons system concept was two to three times greater than that of previous tanks.

From the more than 50 years of armor development in the United States and the Soviet Union, an effective R&D strategy can be abstracted:

- (1) product improvement of existing designs;
- (2) independent development of components and technology; and
- (3) construction and testing of experimental prototypes.

ACKNOWLEDGMENTS

The principal acknowledgment is to Andrew W. Marshall, Director of Net Assessment, Office of the Secretary of Defense, who, in both official and unofficial capacities, has encouraged much of the recent research on the workings of complex government organizations. The unpublished notes and detailed criticism of Oleg Hoeffding require more than the footnote acknowledgment in the section on Soviet doctrine.

I also want to note my indebtedness to the reviewers of an earlier draft who described to me what I knew but did not understand: Nancy Nimitz, John Despres, and Stephen J. Carroll. Wendy Allen and Robert L. Perry were critical and perceptive readers of several sections of this report. Interviews with tank designers, analysts, and other participants in the acquisition process provided both factual details and personal perceptions not attainable from documentary sources.

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I. INTRODUCTION

GOALS OF THE STUDY

The research and development community in which weapons are developed is part of a larger matrix that includes the user of the equipment and his doctrine, the political leadership and their priorities, and society, with its values and capabilities in which the entire R&D process is embedded. The flow of causality in this structure is not unidirectional but multilateral and simultaneous. The generation of new systems does not proceed in a simple, logical fashion; it is conditioned by the complex set of incentives, constraints, and interactions of the participants. Nevertheless, study of research and development yields important insights, for it is there that the outcomes of the entire process become manifest--not in plans, not in intentions, not in theoretical possibilities, but in new military weapons. Often, however, outside forces cannot be ignored. The development of tanks, the subject of this report, is therefore placed in the context of history and doctrine, of personal influences, and of organizational dynamics.

A principal goal of this study is to develop a deeper understanding of the weapons acquisition process in the Soviet Union and the United States. More generally, I would like to explore the empirical relationships that are part of the development of technologically advanced systems, of which weapons are prime examples. Examination of the advancement of a particular technological capability such as tanks in two dissimilar countries over many years should enable the constancies of the R&D process to be observed against a background of shifting institutions and radically different environments. The lessons that emerge should thus be more robust than if based on a single country or a shorter time period.

CONCEPT OF COMPLEXITY

The concept of complexity as it is used in this study and in other analyses of U.S. and Soviet weapons requires clarification. To begin with, the simple dictionary definition of "complex" is sufficient for

present purposes: "characterized by a very complicated, involved, or intricate arrangement of parts."

Complexity is a useful concept when applied comparatively rather than absolutely. That is, a standard of comparison is necessary in order to use the term "more or less complex." Thus, current Soviet tanks are more complex than Soviet tanks of World War II, but less complex than today's U.S. tanks.

Complexity is also more useful when it refers to the mechanisms of equipment rather than to those performance characteristics or attributes that give a product value in use. That is, a distinction should be made between inputs and outputs, between the internal arrangements by which performance levels are achieved and the performance levels themselves.

An important empirical (not definitional) relationship is that between complexity and performance. Systems tend to be more complex as the number of functions that are performed, and the performance levels sought in those functions, are increased. But performance is not the only correlate of complexity. The greater the range of technology from which designers can draw, the lower the level of complexity. For example, today's small hand-held calculators, based on large-scale integrated circuits, are much less complex than their mechanical predecessors, with their gears, levers, and motors. Moreover, these small electronic calculators perform many more functions faster, with greater precision, and cheaper. Thus it is advanced technology that has made this simplicity possible.

Another influence on complexity is design creativity, which may be encouraged or inhibited by R&D strategy or style. For example, flexible, experienced design teams that can respond to the surprises of R&D are more likely to be creative than those that have little continuity and are constrained by rigid, pre-established plans.

In analyzing a system, one should clearly distinguish between its value and its complexity and performance. The links among value, performance, technology, and complexity are elastic. Doctrine and threat introduce important asymmetries into the valuation of weapons. Effective weapons need not be high-performing, multiple-functioned, technologically

advanced systems, and vice versa. Take, for example, the Soviet's World War II tank, the T-34--said by many to be one of the most successful tanks in history. Compared with World War II tanks of Western countries, it was exceedingly uncomplicated (although, as a 30-ton armored fighting vehicle it was certainly more complex than a truck or tractor). The T-34 lacked many of the features and subsystems found on other tanks. The systems it did possess did fewer things, often less well, than those of its contemporaries. And even though the Soviets were considerably less advanced in military technology than other participants in the war, their creative design, judicious choice of functions, and effective development strategy enabled the T-34 to outperform contemporary tanks in the most important tank missions. Twenty-five years later, the Soviet T-62 performed more tasks and demonstrated higher levels of performance than the T-34, but once again it was less complex than tanks designed by the United States and other countries. The T-62 is, of course, more complex than the T-34, but not as much as its increased capability would suggest, since in the intervening years Soviet technology has also moved ahead.

To sum up, analysis of complexity should be comparative or relative--not absolute. It should refer to mechanisms or inputs--not to outputs. Complexity tends to be related to the number of functions, performance levels, technological capabilities, and design creativity, whereas value is only loosely related to the specifications of a system.

SUMMARY OF FINDINGS

Several relationships in the weapons acquisition process will be highlighted in this historically based, summary comparison of U.S. and Soviet armor development: (1) the interactions among development, doctrine, perceived threats, and economic and technological capabilities; (2) the dependency of the style of the development process on the rate of technological change and on the choice of what to produce; and (3) the effectiveness of alternative R&D strategies.

Doctrine, Threat, and Capabilities

A particular weapon's value, and hence the goals of design, are not

independent of national context. Other things being equal, the United States would rationally choose more advanced equipment than the Soviet Union because of its superior level of technology and its efficient production and economic capabilities compared with the overly constrained, planned economy of the Soviet Union.¹ But other things are not equal, and dissimilar values, combined with asymmetrical doctrines and threat perceptions, have resulted in U.S. equipment that is generally more technologically advanced, complex, and costly than relative efficiencies would dictate.

In weapons acquisition, doctrine is the chief determinant of what to produce; the urgency of the perceived threat influences the resources committed; and economic and technological capabilities shape the choice between quality (performance) and quantity. When the process is working well, the requirements of doctrine, threat, and capabilities will not be inconsistent with each other--except perhaps in the short run. Over the long run, the acquisition process (ideally) is interactive as conditions change and as elements of the environment react with each other. For example, new technological opportunities may alter doctrine; or particular technological shortcomings with respect to new threats may call forth additional resources or stimulate changes in procedures directed toward overcoming the technological difficulties. Over the years, the Soviet weapons acquisition process has shown a remarkable consistency. In the United States, however, weapons acquisition activities have proceeded at times with little feedback or interaction. This was especially true of the interwar years.

Soviet doctrine before World War II was derived from a belief that the USSR would have to face an aggressive coalition of the main imperialist powers. The mass use of men and equipment was therefore a necessary condition for survival.² The United States, on the other hand, had very small armies imposed by Congress and a doctrine based on the premise of adequate time for mobilization in case of war. Prewar armor

¹See Section VIII for a more detailed discussion of the Soviet system.

²See Section II for a discussion of Soviet doctrine.

developments reflected these disparities. The Soviet Union each year mass-produced tanks by the thousands, in greater numbers than any other country, whereas total U.S. production in the 20 years between 1919 and 1939 was considerably less than 1000--most of those being machine-gun-armed light tanks built during the rearmament of 1939.

As a result of the absence of native Soviet automotive design and production resources in the early 1930s, the political leadership borrowed Western technology in massive amounts to initiate the armaments buildup associated with the first Five Year Plan. Progress in tank design required broad, parallel advances in all tank subsystems, experiments in alternative configurations, and the assimilation of new production techniques.

The mass production of tanks demanded by Soviet doctrine imposed a requirement for simply designed equipment that was easy for Soviet factories and manpower to produce, operate, and maintain.

The United States, on the other hand, possessed the most advanced automotive and tractor industry in the world, matched by a trained, educated work force. Since annual tank R&D budgets averaged only about \$60,000 during much of this period, tank designers were constrained to take advantage of advancing civilian technology. U.S. Army Ordnance adopted a strategy emphasizing component development, giving lower priority to prototype construction--about one new prototype or modification of an older model was produced each year. Production could hardly be contemplated, especially in a period when unsettled tank technology could quickly make equipment obsolete. U.S. tank development was also influenced by a belief that research could meet the specifications laid out by military planners. Many of the designs that were requested were both unrealistic and inconsistent with budgets and technology.

Throughout the 1920s and 1930s, U.S. doctrine assigned tanks to an infantry-support role (later in this period cavalry roles were added). Large tank units were never contemplated by official doctrine. Most U.S. war plans at that time assumed that large-scale military activities would require (and time would permit) a mass mobilization of armies and production capacity. Given the budgets, doctrine, and national economic

capabilities, U.S. behavior was internally consistent. However, in the absence of warfare, maneuvers, or operational experience, and given the conservative attitudes of a closed military establishment, armor development proceeded in a linear fashion: specifications were drawn in accordance with the principles laid down by doctrine, and research was asked to respond. It was not until the late 1930s that doctrine was amended to incorporate the results of two decades of technological change and the experience from both the initial stages of the European war and domestic maneuvers. It is a measure of the utility of continuous, though modest, development experience that when weapons were required on a large scale with the coming of war, U.S. science, technology, and production could quickly respond.

Following the war, and to a large extent based on the experience of the war, Soviet doctrine continued its prewar emphasis on the importance of the mass use of armor. Tanks are still produced in the thousands, but tank design and production are now a mature industry. As in the 1930s, the constraints of the civilian economy and the costs of producing and maintaining an inventory of some 40,000 tanks have continued to place firm bounds on performance, complexity, and change.

In the United States, postwar doctrine emphasized nuclear-armed, long-range aircraft and missiles. Armor R&D budgets were very small compared with the resources devoted to these strategic weapons, and product improvement based on component developments became the explicit strategy for advancing tank performance. The experimental prototypes that were produced were often novel in concept, though limited in the resources devoted to them. This pattern continued until the late 1950s when, for various reasons, U.S. tank development shifted to the "weapons system" concept of development pioneered by the Air Force. One of the reasons for this shift was the belief that the growing mass of Soviet armor could only be countered by high-quality (i.e., high-performance) weapons, and the application of weapons system strategy to tank R&D was seen as the appropriate method for doing this. Another stimulus behind this strategy was the notion that "nothing is too good for the American fighting man." Ignored was the possibility that if "nothing is too good," nothing may be available. The programs of the 1960s have proved,

in retrospect, to be too expensive and too complex to deploy, and very expensive to develop. Because procurement budgets are not limitless, a high-quality goal for individual weapons has not always been commensurate with overall quality of the fighting forces.

Choice, Style, and Technology

Though conceptually independent, R&D styles are often influenced by the state of technology and the choice of what is to be developed. During stages of rapid technological advance, efforts have concentrated on experimental prototypes and on expanding the technological base. This was especially true of armor development in the 1930s in the Soviet Union and during World War II in the United States. In times of consolidation and maturity, product improvement has been the main source of advancing performance, as illustrated by the postwar years in both countries. When, for reasons of perceived extreme threat, very rapid and large improvements were desired that required the simultaneous development of diverse subsystems and technologies, the weapons system strategy was employed in the United States (but not in the Soviet Union). The same strategy was also employed for less urgent programs. The weapons system strategy was inefficient for the nonemergency development program because it was based on the assumed attainability of preconceived goals and demanded the resources necessary to achieve them, while at the same time it encouraged the participation of outsiders who had contributed their necessary support to establish the program. These programs thus suffered from rigid, overconfident expectations and external interference and lacked the flexibility and internal autonomy required for efficient R&D.

Effective R&D Strategies

From 50 years of armor development, an R&D strategy can be abstracted that appears to have been effective in both the United States and the Soviet Union, in wartime and peacetime, during rapid technological change and periods of consolidation, and with large budgets and small. This long-run R&D strategy consists of (1) product improvement of existing designs; (2) independent development of components and

technology; and (3) construction and testing of experimental prototypes. Technological advance through product improvement and evolutionary change manages the uncertainty of any R&D program largely by placing constraints on the size of the problem. Although evolutionary change cannot be the answer to every demand for increased performance, there is often the potential for extensive improvement through cumulative incremental changes.

The improved elements for incremental change must come from efforts devoted to component and technology development. A potential problem with the component development approach is that either the component or the system may not be available at a prespecified date, and the resources spent on both will have been wasted. This is less likely to occur when there are two ongoing streams of product improvement and component development. Improvements can be made when components are ready, and there is usually a system awaiting improvement.

Product improvement, however, may eventually reach the point of diminishing returns. Experimental prototypes have been historically effective in assessing new configurations, novel combinations, and even wholly new concepts. They are especially useful for determining whether an older product is no longer worth improving and whether a new design ought to be fully developed and produced.

This three-stranded R&D strategy can be applied in quite different environments by varying the emphasis on each of its elements. For example, when technology is fluid and ambiguous, emphasis is on the construction of experimental prototypes and on building up the technological base; during periods of infrequent change, emphasis shifts to product improvement as the chief means of enhancing performance. The findings of this study suggest that this approach is a workable and efficient R&D strategy for developing technologically advanced equipment.

II. THE DEVELOPMENT OF SOVIET ARMOR: DOCTRINE AND USE OF ARMOR EN MASSE

In the 1920s and 1930s, Soviet strategic doctrine, together with a more general theory of war that evolved during that period, called for the mass use of tanks in both the breakthrough and exploitation phases of combat. However, the relative importance of breakthrough and exploitation was hotly debated over the years, and organizational forms were continually modified in an attempt to balance the demands for masses of infantry-assigned tanks for breakthrough missions and for large, independent tank units for exploitation tactics. With respect to tank development and production, the critical aspect of the doctrine was independent of the disputed claims for priority: large numbers of tanks were required for both roles. Indeed, the larger the number, the better *both* uses could be satisfied and the underlying tensions between them relieved.

SOVIET PHILOSOPHY OF MASS PRODUCTION

The demands of mass production and mass use have placed firm constraints on tank design that continue to be felt today. Comparatively simple designs, easy and cheap to mass produce, have characterized Soviet armor since the 1930s. A weapon produced and used in large numbers should also be easy to operate and maintain, reliable, and yet not be markedly inferior to enemy weapons. Standardization of parts, multiple use of components between different models of the same generation, limited change between models of succeeding generations, and, most important, a restrained selection of functions and performance levels have been the means for achieving Soviet weapon design goals.

The fact that Soviet industry is relatively efficient in the design and mass production of this type of system, and relatively inefficient in the production of more complex, high-technology weapons, validates the rationality of the doctrine. That is, the technological and production capabilities of the Soviet economy would themselves direct choice in directions consistent with the requirements imposed by doctrine, and thus doctrine and technology have mutually reinforced

each other. Out of this melange of doctrine and economic capability has come the huge present inventory of some 40,000 tanks and an emphasis on incremental change as the means for increasing quality.

SOVIET STRATEGIC DOCTRINE

The Soviet doctrine of mass, and its interaction with design and production technology, was refined and entrenched by World War II experience.¹ Therefore, to understand Soviet armor development, one must seek out the roots of current behavior and philosophy in the events of past decades.

A general strategic doctrine, derived from a general theory of war, emerged in the Soviet Union in the 1920s and 1930s.² The principal assumptions of the general theory of war were as follows:

1. The USSR, sooner or later, would have to confront an aggressive coalition of the main imperialist powers.
The war aim of the Soviet Union would then be to bring about the destruction of capitalist imperialism.
2. The war would be a long one.
3. The war would require total mobilization of manpower and economic potential.
4. The role of military technology would increase enormously.
Hence, the manpower mass would be reinforced by advanced weapons.

¹General of the Army, I. Pavlovsky, Deputy Defense Minister and Commander in Chief of the Land Forces, confirms the continuing relevance of the earlier experience. "Thirty years have elapsed since the final battles of the Second World War, in the course of which the Soviet Land Forces enriched themselves with experience in the theory and practice of battles and operations.... In spite of the qualitative postwar changes in weaponry and in the methods of their use, this rich experience has not lost its significance and is now an important source of knowledge for training and educating the troops. Scientifically generalized, this experience has found its expression in all manuals of the Soviet Armed Forces." (Pavlovsky, p. 11.)

²There is much in this section that is based on the unpublished notes of Oleg Hoeffding. The doctrine quoted below is based mainly on *Istoriia Velikoi Otechestvennoi Voiny Sovetskogo Soiuza, 1941-1945* (hereinafter cited as *IVOVSS*), Vol. 1, pp. 436ff., and on Sokolovskii, pp. 165-172.

5. Military operations would be marked by great mobility over a broad geographical domain--after an initial breakthrough of the enemy's position.

A dual mission for tanks evolved from this theory. In the breakthrough phase of combat, tanks were envisioned as providing close support for the infantry. For exploitation of the breakthrough, highly mobile mechanized forces would engage in deep offensive operations. The "breakthrough" requirements led to the "assault army" concept in the late 1930s that called for a density of 50 to 100 tanks per kilometer in the breakthrough sectors.³ Similarly, independent exploitation units required large numbers of tanks to sweep over and overwhelm the extended areas described by operational doctrine. By the late 1930s, both the general theory of war and the strategic doctrine derived from it had a reinforcing logic that led to a requirement for tanks *en masse*. Soviet sources maintain that this doctrine was novel, but it had great similarity to the German Blitzkrieg doctrine and to Liddell Hart's theories of tank warfare.

ORGANIZATION OF TANK FORCES

Although the main elements of the strategic doctrine were formulated in the late 1920s, its translation into reality had to wait until the Soviets developed both a tank design and a production capability. In 1929, the establishment of the Armored Tank and Mechanized Forces, the publication of tactical-technical requirements for future tanks, and the long-range plans adopted for the buildup of the armored forces were all consistent with the demands of the enunciated doctrine. The acquisition schedules were so demanding, according to a recent history, that foreign designs and production techniques were purchased "to

³ Even in the last stages of World War II, when production rates exceeded attrition, frontline densities never exceeded 25 tanks per kilometer in the close support role. However, in the multiechelon breakthrough formations developed during this period, total tank densities exceeded 50 tanks per kilometer and were as high as 115 in the Vistula-Oder operation in the First Byelorussian Front in January 1945. (Matsulenko, pp. 54-55.)

expedite the development and production of tanks."⁴ Production and further refinements of the tanks introduced in this period were accelerated, and total production from 1928 to 1937 was approximately 21,000.⁵ By the end of 1937, the Red Army had some 15,000 tanks in its inventory,⁶ and by the time of the German invasion, tank strength could very well have been at a level of 20,000 as claimed by several Western analysts.

Organization of tank forces proceeded apace with the mass production of equipment and the requirements of doctrine. An experimental mechanized brigade was formed in 1929-1930, and the first Mechanized Corps was formed in 1932.⁷ Formation of more and bigger Mechanized Corps began in 1937 with a planned strength of over 500 tanks per corps. Four such corps existed in mid-1938.⁸

From maneuvers and their combat experience in the Spanish Civil War in 1936 and in the Far East in 1938-1939, the Soviets became aware that the growing mass and density of armor, as organized into Tank Corps, "proved cumbersome and difficult to command.... After exhaustive study of tank force combat experience," the Main Military Council, in November 1939, ordered the four Tank Corps disbanded and reformed into smaller brigades with 258 armored vehicles.⁹ The same decision established 15 new Motorized Tank Divisions. Within about 6 months, this reorganization was said to have been basically completed. Thus, what may have been condemned as organizational "gigantomania" had been corrected with the disbandment of the Tank Corps. It must be noted though that these new forces were still organized into comparatively heavily armored, mobile, division-size formations.

⁴Mostovenko (1966), p. 15.

⁵IVOVSS, Vol. 1, p. 65.

⁶Kosyrev, p. 43.

⁷This Mechanized Corps was possibly the world's first such organization.

⁸For comparison, Germany had 3 Panzer divisions in 1937 and 6 in late 1939, each with about 300 tanks.

⁹Krupchenko, pp. 11ff.

The 1939-1940 reorganization was remarkably short lived. In June 1940, the Defense Commissariat "reopened the question of tank force organization" and the Soviets decided, in effect, to reverse their previous decision and establish a new Mechanized Corps. The period of the next 12 months could aptly be titled "From Tank Mass to Tank Mess." The new corps called for 36,000 men and more than 1000 tanks. Unaccountably, the provision of modern T-34 and KV tanks to these new formations was held up because "nearly up to the outbreak of the war, the Defense Commissariat had no firm opinion in regard to the T-34 and KV, although they had already been accepted. For this reason, industrial production of the new tanks was delayed."¹⁰ Twenty-nine new corps were to be established, but as they were to be supplied simultaneously, most of them were not fully equipped at the outbreak of World War II. In the meantime, the bulk of the tank mass consisted of older models, many of which were in disrepair, partly because the new models were expected. Because the new tanks were slow in being supplied, the Military Districts decided to have the old tanks repaired and requisitioned spare parts from industry. "However, the industrial commissariats accepted only 31 percent of the requisitions and by June 1, 1941 had actually delivered only 11 percent of the spare parts required."¹¹ On the eve of the German invasion, only 27 percent of the old model tanks were in operating condition. Thus, at the time when the long-predicted battle against a heavily armed, imperialist, capitalist nation was imminent, the theory, doctrine, design, production, and organization of the previous decade and a half were not effectively brought to bear against the invaders.

WORLD WAR II EXPERIENCE

The massive attrition of Soviet armor in the first few months of the war, caused in part by the initial German attacks and by unsuccessful

¹⁰ IVOVSS, Vol. 1, p. 415. Only 68 percent of the appropriations for tank and related equipment procurement was spent in 1938; by 1939, expenditures were still only 92 percent of appropriation.

¹¹ Ibid., p. 475.

attempts to mount counterattacks, very soon led to the collapse of the major independent armor formations. First the corps and then the divisions were disbanded and the equipment was transferred to tank brigades. By the winter of 1941, "all tank units and formations were incorporated in combined-arms armies."¹² The dispersal of tanks among the infantry--enforced by the necessity of events rather than by the choice derived from doctrine--had become complete, but not for long.

From the time of the battle of Moscow in December 1941 until the end of the war $3\frac{1}{2}$ years later, the overall trend would be for tank production to outnumber losses. With the increased flow of new tanks from the reestablished plants east of the Urals, the Soviet Army was able to reconsider the organization of their tank forces, especially in light of the lessons learned in their successful counteroffensive before the gates of Moscow. As production began to meet the demand for the massed use of tanks, the Tank Corps was revived, later to be followed by Tank Armies. The new Tank Corps, however, was much smaller than its 1940 predecessor. It consisted of 5600 personnel and only 168 tanks.

The Soviet counteroffensive at Stalingrad in November 1942 was, for Soviet armor, the first successful application of the old doctrine of using powerful tank formations in a rapid and sweeping "exploitation of the breakthrough," while at the same time providing strong tank support for the infantry by lesser units.

The ability of the Soviets to recreate a mass of armor during a devastating war on their own territory permitted them to successfully apply their established doctrine. Their production organization and producible weapon designs were of crucial importance to the success of their tank forces. In fact, the output from the tank factories allowed them to indulge in a lavish, even reckless, use of armor.

For the battle of Kursk in July 1943, the Red Army assembled almost 5000 tanks and self-propelled guns. According to one Soviet expert, "the Kursk battle showed once more that only the massed use of tanks can ensure the success of counterblows. However, experience

¹²Krupchenko, pp. 41-42.

in the Orel operation showed the *inexpedience* of using Tank Corps and Armies for the breakthrough of *position defenses* [that is, well prepared, fortified defenses] as they suffer heavy losses in carrying out such tasks."¹³ The most effective use of tank masses "was for operations in the deep rear of the enemy," whereas only infantry support brigades helped in the actual breakthrough.¹⁴ A successful breakthrough of prepared defensive positions was seen to require a massive concentration of combined-arms armies along a narrow breakthrough sector. This required reconnaissance in depth, mobility, and surprise. It could not be done with mass alone. Herein lay a dilemma for the organization of armored formations: What was the optimal allocation of armor for infantry support in breakthrough relative to that for deep penetration and exploitation missions? This dilemma could only be solved by producing enough tanks to satisfy both requirements. For the rest of the war, inconsistencies occurred between the formal organization of tank armies designed for deep exploitation and the actual detachment from these armies of brigades for infantry support.

Advocates of both breakthrough and exploitation tactics continued to debate the supremacy of each until the end of the war and up to the present time. This tension is now somewhat relieved by a stock of Soviet armor that far exceeds the number of tanks available during World War II and any number likely to be met on today's battlefields. Also, the highly tank-intensive breakthrough mission formerly executed by the Soviet ground forces is now assigned by postwar doctrine to nuclear weapons.¹⁵

Despite the appearance of new antitank weapons and a considerable controversy prior to the mid-1960s regarding the future role of tanks in an era of nuclear warfare, tanks *en masse* is an historically based

¹³ Ibid., p. 143.

¹⁴ Ibid.

¹⁵ "The breakthrough of enemy defense will rarely be the main task of the Ground Forces, and certainly not the 'gnawing through' of defensive positions. The breakthrough of the defenses is now no longer such an acute problem as it was in the past." (Sokolovskii, p. 370.)

concept made concrete by the experience of a war that continues to influence Soviet force posture.¹⁶ Thus the development of Soviet armor seemingly cannot be divorced from the requirements imposed by the tanks *en masse* doctrine.¹⁷

¹⁶ In fact, expectations of very heavy attrition in tactical nuclear warfare (stressed in Soviet doctrinal writings), or even in non-nuclear combat (stressed in Mideast war experience), may have added a new "multiplier" to armor requirements.

¹⁷ The doctrine of tanks *en masse* is summarized by the reverie of a commander of the armored forces, Marshal Rotmistrov. "The best situation for a tank commander is to be in command of large groups-- a brigade, a corps, an army.... A concentration of a thousand tanks-- this is the dream of every tank commander." (Quoted by Milsom, p. 56.)

III. THE DEVELOPMENT OF SOVIET ARMOR, 1924-1932: THE BEGINNINGS

Soviet tank development can be divided into four distinct phases that are substantially different from each other and that establish the bases of behavior of subsequent phases. Soviet armor had its beginnings in the years of the first Five Year Plan when the foundations were laid for a modern, native capacity to design, produce, and field tank forces. The 1930s were years of experimentation and ferment during which the Soviets learned the art of design and production by turning out scores of prototypes and producing close to 3000 tanks per year. By World War II, the Soviets had developed several outstanding designs that would be produced in quantity during the war. Since 1945, product improvement, together with continued high production rates and incremental change, has enabled the Soviets to maintain their status as the possessors of the world's largest tank army.

The T-34, designed in the late 1930s, was one of the most successful tanks ever built. It exemplifies a development strategy that is highly effective, namely, a strategy of product improvement, component and technology development, and experimental prototype construction and test. In fact, most of the history of Soviet tank development can be described within the context of this strategy, with the experimental approach being emphasized in the 1930s and product improvement predominating since World War II.

CENTRALIZED RESPONSIBILITY

Although armor production can be traced back to the days of the czars, the technology was crude by world standards, and design groups and production centers were small and scattered. A lack of continuity prevented the Russians from accumulating experience. Talented and experienced tank designers were so rare in 1922 that the War Industry Council advertised an open contest in the Red Army newspaper offering prizes for the best tank designs.

In mid-1924, responsibility for tank production was centralized in a new tank bureau of the Main Administration for Military Industry

(GUVP). The chief of the bureau, F. E. Dzerzhinsky, was also the chairman of the All Union Council of the National Economy, thus giving tanks a special prominence at the national level.¹ Continuity and centralization of design and production were encouraged by the new bureau. The design organization was colocated with the producing plants--an association that was to continue into later periods.

The 1927-1930 period produced several experimental models, prototypes, and small production runs of 25 to 30 units, but a successful design was not produced, chiefly because the Soviets lacked experience in technical design and especially because of the primitive state of their automotive industry.² Nevertheless, these first attempts (seven designs were initiated) provided the necessary experience to assimilate and improve upon foreign tank technology in the early 1930s.

Cooperation with Germany was attempted in 1927 through the establishment of a tank design center and school at Kazan. This cooperation turned out to be unproductive partly because the Germans were unwilling to share their newest technology with the Russians.

PARTY INITIATIVES

Matters relating to the inferior state of armor became the subject of Party Central Committee discussions. In 1929, the Party ordered that steps be taken to secure "in the course of the next two years, the manufacture of experimental models of all modern types of tanks."³ In 1930, a Department of Mechanization and Motorization was established at the Leningrad Military-Technical Academy, and a similar department was organized in the civilian Lomonsov Auto-Tractor Institute in Moscow. Two years later, these two organizations were merged to form an

¹Prior to this time, armored equipment was under the Artillery Administration of the Army, and production fell under the umbrella authority of the GUVP. (See Mostovenko (1966), p. 12.)

²The most successful of these early attempts was the MS-1 (T-18), of which more than 900 were produced between 1928 and 1931. This was a 6-ton vehicle with a 37-mm cannon, derived from the French Renault light tank of World War I. Associated with this design were many of the leading members of what was to become the T-34 design team of a decade later.

³Mostovenko (1966), p. 15.

independent academic organization--the Stalin Academy of Mechanization and Motorization of the Red Army. The Academy, an elite educational and R&D institution, trained senior commanders for the armored forces, as well as tank design and production engineers (including Kotin, chief designer of the KV heavy tank of World War II). Into this central place within the military were gathered the major functions of education, experimentation, test, and exploration of the uses of armor.

Trade missions were sent to Czechoslovakia, Italy, and Germany, and in 1931, a special commission visited Great Britain and the United States to purchase advanced tanks and licenses to manufacture them. Several British Vickers tank models and an American Christie design were accepted for production in 1931.⁴

As these developments got underway, a major bottleneck was the lack of a mass production tractor and automotive industry, and of supporting component industries. The Gorki Automobile Plant (GAZ), modeled after Ford's River Rouge plant, began construction in 1929 and started operation in 1932. The Stalingrad Tractor Plant, also designed and built by United States firms, was begun in mid-1929. The Kharkov and Chelyabinsk Tractor Plants were closely modeled after the Stalingrad factory. By the early 1930s, the backbone of Soviet industrial capacity in the automobile and tractor (and tank) industry was substantially in place, and was largely designed, and often actually constructed, by Americans.⁵

⁴War Commissar, K. E. Voroshilov, commented on this period in 1933: "Up to 1929, these few dozen [captured] tanks had to serve as models for the whole Red Army to receive its training and 'education.' We exhibited these tanks in our parades and they naturally raised smiles from the foreign attaches.... But there was no smile on *our* faces. In 1927 we were able to construct our own tank, but this tank was not a success, its fighting qualities being but little in advance of the old Renault.... The difficulty was that up to 1928 we had no cadre of skilled technicians who could implant the technique of tank production in the Soviet Union. Therefore we were compelled--and quite rightly too--to take the line of securing foreign makes." (Quoted by Erickson, p. 303.)

⁵The transfer of design, construction, and production technology to the Soviet Union during this period was seen in many other industries. (See Sutton.)

The Soviets produced enough tanks of native design in the late 1920s to form their first mechanized units, which they quickly subjected to experimental trials and maneuvers.

Thus, by 1932, the research, design, test, and production facilities were in place that would propel the Soviet Union to the forefront of armor technology and production by the time of the German invasion less than a decade away. The events of the next several years would give impetus to these new organizations and provide valuable lessons for the development of modern armor.

IV. THE DEVELOPMENT OF SOVIET ARMOR, 1932-1939:
YEARS OF EXPERIMENT AND LEARNING

Six different tank types were in production by 1932 as mass production, stimulated by the danger of a Japanese invasion, began in earnest. The three light tanks (T-26, T-27, and T-37) were all based on Vickers designs. The American Christie M1931, with some simplification of design, gave rise to the BT series fast tank.¹ The medium T-28 resembled the British Vickers 16-ton A6/Mark III in layout, but the Soviet tank was 13 tons heavier and carried a much larger 76.2-mm main gun (compared with the 47-mm 3-pounder on the British vehicles). The design of the Soviet heavy T-35 was also influenced by Vickers experience--this time by the multiturreted "Independent." However, the Soviet tank was again considerably heavier and carried the larger 76.2-mm gun. This design may also have been influenced by heavy-tank experience gained from the Germans at Kazan.

The desire at this time was to build up the tank forces as quickly as possible, to provide experience and training in the use of tanks, and to organize design and production skills. The use of foreign technology at this stage provided a ready-made foundation for rapid development and deployment, which, in turn, created a demand for an enlarged design and production capacity.

NEW TANK DESIGN GROUPS

In 1933, the Party Central Committee increased the flow of academic talent into the tank design cadres. A group of students at the elite Leningrad Polytechnic Institute (including M. I. Koshkin, chief designer of the T-34) was directed to work on their diploma projects at one of the tank plants. At the same time, engineering faculty members from

¹A strict weight classification would place the BT series in the light-tank class, but since it evolved into the T-34 medium tank, and since it was intended to be used more like a medium tank than a light one, it will be convenient to categorize it as a medium tank here.

other higher educational institutions were encouraged to "join the tank industry."²

Thus, by 1933, there were three main sources of tank designers, some of whom were to become famous for their designs in World War II. Out of the tank bureau (GUVV) program that began in 1924 came Morozov, Kucherenko, Tarshinov, and Bondarenko of the T-34 design group. The 1932 Stalin Academy of Mechanization and Motorization (including the civilians merged into the military academy) produced Kotin and Ermolaev of the KV design group. Students and faculty directed into the tank industry in 1933 included Koshkin (T-34) and Dukhov (KV).

EXPERIMENTAL UNITS

Throughout this period, experimental units and brigades were formed to test the new equipment and to develop techniques for using new technology. Exercises and maneuvers were part of the scheme to train the Russian soldier to handle this modern equipment and to provide designers with operational evaluations. Immediately after its founding, the first mechanized brigade took part in exercises that aided in shaking down the organization. Joint maneuvers were carried out with the other military arms to develop techniques for the combined use of armor, aircraft, and artillery.

Some of these exercises were an integral part of the development process. Milsom writes that the Soviets considered it necessary to produce a sufficient number of light tanks in 1930 for collective experimentation before embarking on large-scale production.³ Tactical studies at the Main Military Staff College were aided by an experimental tank unit. Large-scale combined-arms maneuvers were held at Kiev in 1935 and at Minsk in 1936. British General Wavell commented on the 1936 exercises that "over a thousand tanks marched past us on

²Mostovenko (1958), p. 115. Included in this group from the civilian educational institutions were several members of Kotin's heavy-tank design group.

³Milsom, p. 37.

parade, and the worst we saw was a few engines missing fire a little at times."⁴

Experimental use of equipment, together with exercises and maneuvers, thus became an integral part of the development of new armor technology. In this way, the users, as well as the designers, were able to discover technical weaknesses, and to evaluate technology in terms of tactics and military applications.

A PERIOD OF EVOLUTION

Several of the early tank models were found to have limited application or to be technically unsound. The T-32 heavy tank, and its successor, the T-35, proved to be tactically and technically unsuccessful and were only produced in limited numbers.⁵ Nevertheless, the T-35 was produced from 1933 to 1939, but at a rate of less than one per month.

The light tanks went through continuous evolution. Between 1931 and 1938, the T-26 increased its range from less than 100 mi to more than 200 mi, maximum armor thickness increased from 15 mm to 25 mm, and the 45-mm gun replaced the 37-mm cannon as the main armament. The T-26 series spawned the T-46, which combined the high-speed Christie running gear of the BT series with the hull and turret of the T-26. A second offspring, the T-50, was more heavily armored and had an improved suspension and a cast turret. Although this tank proved to be too complex and expensive, the Soviets gained sufficient experience from its design and application, and from an experimental prototype, the T-30, to produce the T-40. The heavily armored T-40 was not completely successful either, although it went into series production. However, the extensive experience provided by all of these models, coupled with developments in the medium-tank field, led to the design and production of the T-60,

⁴On the basis of this experience, Wavell recommended that the British look into the American Christie design on which the BT tanks were based. Shortly thereafter the British purchased a model from Christie that was developed into the A-13 Crusader and Cromwell.

⁵The T-32, a heavy tank, should not be confused with the T-32, a medium tank, that was the direct predecessor of the T-34. Soviet tank nomenclature has never been fully elucidated.

T-70, and T-80 series, which saw much use in World War II. Over 8000 T-70s were produced. These tanks were characterized by their low cost, which was due to the use of automotive components and to their production on automotive assembly lines.

The experience that the Soviets had gained in a decade of tank design, experiment, prototypes, and production models culminated in the design and production of the T-34 at the end of the 1930s.⁶ Almost every subsystem--including the gun, engine, suspension, armor shape and thickness, and general layout--had appeared in earlier tanks. The T-34 was the epitome of creative design, the assembly of a new and peculiarly valuable configuration from a pre-existing set of elements.⁷

The KV (Klementy Voroshilov) tank, developed in 1939, followed a development path similar to that of the T-34. Although heavy-tank design was limited in the 1930s, the designers of the KV benefited from the same experience as the T-34 design group. In fact, many of the same subsystems appeared in both tanks, although a new form of torsion bar suspension, a major innovation, appeared on the KV.

Throughout this period, production technology and capacity had kept pace with product technology. Construction and refinement of the new automotive and tractor industry enabled the product designs to be produced in rapidly expanding volume. In 1932, 3500 tanks were produced, and production rates continued at about 3000 per year through 1937. The purges of the next 2 years disrupted production, but by the end of the decade output had recovered to over 2000. Even while new designs were coming off the drawing boards and entering production, many of the older tanks continued to be produced, possibly as a precaution against deficiencies in the new designs or difficulties in their production.

⁶ A detailed account of the development of the T-34 is given in Section V.

⁷ One of the best examples of an American design with these characteristics is the Douglas DC-3 aircraft and its many descendants. The engine, fuel, engine placement, structures, wing planform, control surfaces, cowl, etc., had all appeared in earlier aircraft--most of which were not originally developed by Douglas. (Phillips, pp. 115-121.)

The development of the armored vehicles on which the Soviet Union was to rely during the coming war grew out of the tremendous amount of experimentation, development, production, and testing that had gone on in the relatively brief period of the previous decade. Thirty different models were developed during those years, but at the beginning of the war with Germany, production was quickly concentrated on three main types--the T-60 light tank, T-34 medium tank, and KV-1 heavy tank.

The development of armor in the 1930s was a consciously planned activity, often personally directed by Stalin himself. It began when the Soviets came to grips with the fact that their technology was not up to the task of developing and producing modern weapons. This realization was colored neither by Party dogma nor by false bravado, but was based on a clear assessment of important deficiencies.

PREWAR SELF-PROPELLED GUNS

Quite a different story can be told about the development of self-propelled guns during this period. The responsibility of the Main Directorate of Artillery (GAU), an organization with deep roots in the czarist period, these weapons saw little of the high-level priority devoted to tank development.⁸ In 1925, and for several years thereafter, the GAU was preoccupied with developing a 76-mm regimental gun on a "special tracked chassis." Since there was no established tank industry at that time, the chassis had to be developed in addition to the gun itself. In the early 1930s, the Commission on the Mechanization and Tractorization of the Army under GAU was instructed to provide artillery with cross-country capability, using the chassis of tanks in serial production, which were, by this time, the responsibility of an independent directorate. In 1933 and again in 1937, the Revolutionary Military Council issued requirements for mobile, self-propelled artillery ranging from 76-mm guns to 203-mm howitzers. By the end of the 1930s, 12 types of guns had been developed according to these demands, but very few had been produced. Although serially produced chassis had been prescribed, the artillery designers became absorbed with

⁸See Kosyrev, pp. 41ff., for details on pre-World War II developments.

larger weapons that required a specially designed chassis made up of "elements" of the T-28 and T-35 tanks. A tendency toward gigantomania was observed with a 254-mm gun, 305-mm howitzer, and 400-mm mortar.

One source suggests that the prewar failure to produce these designs was based on "an underestimation of this new weapon" and on the development of heavy tanks with larger-caliber guns.⁹ However, no tank carried a gun larger than 76-mm until midway into the war. Other reasons for the nonappearance of self-propelled guns were perhaps as important: responsibility was divided between artillery and the tank organizations; the competition for tank chassis was unwelcome during the buildup of Soviet tank forces; and the gigantomania of the artillery planners led to very complex vehicles that would have been difficult and costly to produce and operate.

⁹Ibid., p. 43.

V. THE DEVELOPMENT OF SOVIET ARMOR: EVOLUTION OF THE T-34

The Soviet's best-known and most successful tank was the T-34. Based on the Christie M1931 design, the T-34 took only 8 years to develop. It is an almost perfect example of the effective R&D strategy that has been responsible for Soviet and U.S. tank developments. This three-stranded strategy consists of (1) product improvement of existing designs; (2) independent development of components and technology; and (3) construction and testing of experimental prototypes.

The T-34 development made use of each strand, and all three were essential for the final outcome. Product improvement of the BT series permitted the design to be gradually refined with only a limited amount of uncertainty at each stage. It also revealed those areas where major design changes were needed. The results from component development--engine, suspension system, armor, and guns--were fed into the product-improvement stream and into a host of experimental prototypes. The experimental vehicles tested out new configurations and components in the context of an integrated system. But most important were the preceding years of continual experiment, improvement, and design that provided the experience and training for the designers to make the best choices from the menu of alternative technologies.

SALIENT FEATURES

The T-34 had a number of features that contributed to its success: low cost and producibility; a well-shaped, heavy armor; an efficient diesel engine; a well-protected, rugged, independent suspension system; a low silhouette; and a high-velocity 76-mm gun. Individually, all of these features had appeared on other Soviet tanks. Their combined use on the T-34 was an example of design creativity enhanced by the result of knowledge gained from previous experience, component and subsystem development, and alternative configurations.

Producibility was emphasized from the beginning. Christie's M1931 tank was redesigned for simplicity and was first produced as the BT-2 in 1932. Several variations followed, and production rates were increased.

Armor Plate

During this period, the Soviets learned new techniques for welding, riveting, and casting armor plate. Electrically welded plates, which greatly speeded production, appeared on a light tank, the T-26S, in 1938.¹

The sloping armor plate first appeared on the BT-IS, an experimental outgrowth of the BT series, in 1936. This armor, however, was only effective against low-caliber bullets and fragments. Experiments with armor shapes showed that a conical turret had good antiballistic properties. The T-111 (T-46-5), an experimental prototype based on the BT-IS, carried 60-mm armor on both the turret and the hull, but its 45-mm gun was too small for such a heavily armored vehicle. The Soviets' combat experience in Finland in late 1939 had confirmed the need for heavier armor, and the last versions of the T-28 (produced from 1932 until the beginning of World War II) were equipped with 80-mm armor by attaching additional armor "screens" to the turret and hull. Thus, by the end of 1939, the shape, thickness, and fabrication of heavy armor required for protection against the newer antitank guns had been proven to be technically feasible and producible.

Engine Design

With the heavier armor, a more powerful tank engine was desirable--and available--both to retain the tank's present mobility and to provide additional cross-country mobility. A government directive in 1932 had authorized development of a diesel tank engine.² By 1934, the design

¹Khrushchev tells of being approached by the director of the Electro-welding Institute, Ye. O. Paton, around 1938. Khrushchev was then First Secretary of the Ukrainian Central Committee. Paton showed him a new technique for fusion welding. Khrushchev later mentioned this technique to Stalin, and Paton was subsequently charged with introducing it to industry. Khrushchev then sent Paton to the Kharkov tank factory to see if the new technique could be used for welding armor plate. The technique worked, and "tanks started coming off our assembly lines like pancakes off a griddle." (Khrushchev, p. 117.)

²Some sources claim that this engine was a copy of a French Hispano-Suiza aircraft engine, but detailed comparisons by British analysts after World War II do not support this claim. However, the Soviet Union was

of this engine had progressed far enough so that a development plant could be established at the Kharkov Locomotive Plant to produce the first units. By the end of 1935, a 400-hp, 12-cylinder diesel engine was tested in a BT-5 tank. In 1938, after further development and improvement, the V-2 diesel, with an output of 500 to 600 hp, was ready to be mounted in the production BT-7M.

The improvement gained from this new engine can be demonstrated by comparing the range of the gasoline-powered BT-7 with that of its successor, the BT-7M. Range increased from 275 mi to 400 mi, even though the weight of the tank also increased by a ton. The Soviets also claimed that this revolutionary engine (it was the most powerful diesel tank engine at that time) was more easily maintained, less flammable, easier to start, and created less radio interference than gasoline engines. Its fuel requirements also made smaller demands on the nation's limited petroleum refining capability.

Suspension System

The increased loads generated by the powerful new engine and the greater weight of the armor forced a reconsideration of the suspension system. All of the tanks in the BT series and their derivatives were designed for moving on either wheels or tracks. This dual drive equipment was intended to permit the tank to travel on its wheels at high speed on hard-surfaced roads. When the tank moved off hard surfaces, the tracks would be mounted and it could then travel over unsurfaced terrain. However, this system required complex suspension, steering, and drive mechanisms that were expensive to build and difficult to maintain. The original Christie M1931 design had all of these features, but the most important element of the design was the independent suspension system and great vertical movement of the road wheels. Throughout the 1930s, the suspension systems of the various tanks that had been produced were undergoing continuous experimentation, development, and test. By the late 1930s, eight different suspension systems

importing great quantities of Western technology, including engines, in the late 1920s and early 1930s, and some features of the imported designs could be expected to turn up in almost any new Soviet equipment of that era.

had been used on production tanks, and more were in the experimental stage. Based on this technical experience, and the tactical lessons gained in combat in Spain and the Far East, designers Koshkin and Morozov sent an historically important document to the Soviet High Command in 1938:

In view of the tactical reluctance to employ the BT tanks in the wheeled mode, added to the difficulties in technology associated with producing a tank which is able to travel on both wheels and tracks as required, it is suggested that future efforts should be directed towards the development of a less complex vehicle, running on tracks alone and employing the coil-spring (Christie independent) suspension of the BT series.³

The designers, on their own initiative, began work on a pure track tank--the T-32. They based it on a 1938 wheel-track prototype--the A-20; this tank carried the new diesel engine and heavy, well-shaped armor, but it mounted only a 45-mm gun (a sister tank, the A-30, carried a 76-mm gun). The T-32 design was approved by the Main Military Council in August 1938, but heavier armor was suggested. According to Soviet tank historian, V. Mostovenko, both the A-20 and T-32 were presented for consideration to the State Commission in the summer of 1939, but it made no decision as to which model to accept. (The Commission did, however, ask for still heavier armor.) Further tests did not clarify the question, but only the combat experience in Finland at the end of 1939 resolved the problem in favor of the pure track version.⁴ An improved version of the T-32 became the T-34, which had the pure track system.

The Low Silhouette

The low silhouette of the T-34 came from two principal sources. The flat-track system was a distinctive characteristic of the BT-series tanks and was used on the T-34. In this system, the track does not return over rollers, but rests directly on the tops of road wheels. The

³Quoted in Milsom, p. 103.

⁴Mostovenko (1966), p. 19.

absence of return rollers can reduce the height required in the hull. A major disadvantage of flat-track systems is that they usually run slack, which increases the likelihood of their being shed. The second feature that reduced the height was the emphasis on a very low turret. Stalin continually stressed the expediency of reducing tank height by lowering the turret. In 1938, he called in the two leading designers, Kotkin and Morozov, and emphasized the requirement for, among other things, decreased turret size.⁵ The small size of the turret was not achieved without cost, however, because it restricted the depression of the main gun and limited the room for crew operations and ammunition storage in the turret. Thus, the low silhouette was obtained in exchange for other desirable features. Nevertheless, this tradeoff appears to have increased the tank's military value, as is shown by the success of the T-34 and by the continuation of these design features right up to the present models.

Upgrading Tank Armament

With the development of higher-velocity, antitank guns in foreign armies, the Soviet Union found it necessary to upgrade their armament to meet the challenge of their potential enemies. Together with the heavier armor that was undergoing development, the acquisition of a long-range, high-velocity gun would allow Soviet tank forces to face either opposing tanks or antitank artillery with relative immunity.

The T-28 medium tank and all of the heavy tanks had carried 76.2-mm guns since 1932, but these had low muzzle velocities. Some of the early BT series, however--the BT-3, 4, 5, and 7--carried a high-velocity 45-mm antitank gun, with a muzzle velocity of 2350 ft/sec, that was quite effective for the mid-1930s. By 1937, however, the T-111 (T-46-5), which was equipped with the same 45-mm gun, was rejected because the armament was considered too light for the anticipated combat environment.

The length of the 76-mm gun was gradually increased during this period from 16.5 calibers in 1932 to 24 calibers in 1938, but the muzzle

⁵At this meeting, Stalin also emphasized increased armor, improved tracks, and longer range. (Milsom, p. 53.)

velocity was still less than 1200 ft/sec.⁶ A few models of the SMK and T-100 heavy tanks, with their 76-mm guns of 24 calibers, were used in the Soviet-Finnish encounter in 1939 and quickly proved that this level of firepower had little effect on modern defenses. This experience resulted in a new requirement for a high-velocity gun. A 76-mm gun of 30.5 calibers and a muzzle velocity of 2200 ft/sec was the outcome. (In comparison, the velocity of the short 75-mm gun on the German PzKw IV tank was, at that time, only 1240 ft/sec.) This gun was first mounted on the A-30 prototype in 1938, but the turret had been designed for a 45-mm gun and was too small to accept the larger weapon comfortably. Both the T-32 and the new KV-1 heavy tank were specifically designed to carry the longer artillery. The first models of the T-34 also carried this gun, which made it one of the best armed tanks in the world.

Transmission Problems

From this discussion, it can be seen that almost all of the T-34 subsystems and design features had appeared in previous tanks, and that the designers had drawn heavily on experience gained in development, manufacturing, and combat use. One digression from this general policy, however, confirmed the utility of the Soviet R&D strategy. Upon receiving instruction from the Main Military Council, in August 1939, to refine the design of the T-32, Morozov (who was to become chief designer of the T-34 a year later with the death of Koshkin) proceeded to design a new transmission for the T-34. The first production units were so unreliable that tanks were sent into battle with spare transmission units cabled to the deck. The transmission problems were only partially solved with the appearance of the T-34F in 1943. Stalin Prizes at that time went to the two engineers responsible for the new transmission design--chief designer Morozov and Kucherenko (who had also designed the hull).

⁶The length of a gun in calibers is defined as the barrel length divided by the diameter (caliber) of the bore. Longer barrel length is a means for attaining higher muzzle velocity of the projectile by allowing more complete combustion of the propellant within the barrel.

EVALUATION OF THE T-34

The decade of the 1930s thus saw the Soviet Union raise itself from a position of inadequacy in virtually every aspect of tank design and production to a level of supremacy unmatched by its enemies or allies. This fact is attested to by the judgments of experienced tankers, students of tank warfare, and by those who had to fight against Soviet tanks.

In the first engagements between German tank forces and Soviet units equipped with their new T-34s, the German tankers in their PzKw IV's were shocked by the ability of the Soviet tanks to move rapidly where the Panzers were floundering, by German shot bouncing off the armor of Russian tanks, and by the devastating effect of the powerful Russian guns on the German armor. General Heinz Guderian, the German armor theoretician and commander, tells of reporting to his superiors about his first encounters with the T-34: "Up to this point we had enjoyed tank superiority. But from now on the situation was reversed. I described in plain terms the marked superiority of the T-34 to our PzKw IV.... I concluded by urging that a commission be sent immediately to my sector of the front and that it consist of representatives of the Army Ordnance Office, the Armaments Ministry, the tank designers, and the firms which built the tanks."⁷ Such a commission was in fact assembled and was almost unanimously advised by the Panzer officers to copy the T-34 with only minor modifications. This advice was rejected by the German designers because it would not be possible to mass-produce essential elements of the T-34, particularly the aluminum diesel engines.⁸

Another German armor specialist, General F. W. Von Mellenthin, also evaluated the T-34 as far superior to any tank on the German side. "The Russian tank designers understood their job thoroughly; they cut out refinements and concentrate on essentials--gun power, armor, and cross-country performance."⁹

⁷Guderian, pp. 182-183.

⁸Ibid., p. 215.

⁹Von Mellenthin, pp. 359-360.

Liddell Hart described the T-34 in terms that can still be used to describe Soviet weapons:

The machines were rough inside and out.... Their design showed little regard for the comfort of the crew. They lacked the refinements and instruments that Western tank experts considered necessary as aids to driving, shooting, and control....

On the other hand, they had good thickness and shape of armor, a powerful gun, high speed, and reliability--the four essential elements.... Regard for comfort and the desire for more instrumental aids involve added weight and complications of manufacture. Such desires have repeatedly delayed the development and spoiled the performance of British and American tanks. So they did with the Germans, whose production suffered from the search for technical perfection.¹⁰

¹⁰ Liddell Hart, p. 181.

VI. THE DEVELOPMENT OF SOVIET ARMOR, WORLD WAR II: TANKS EN MASSE

During the years of World War II, the emphasis in Soviet armor was on mass production and mass use of tanks. Stalin continually insisted that nothing was to interfere with production.¹ Large-scale production of tanks, while of primary importance during the war, had been standard practice in the Soviet Union since the early 1930s. Several estimates place the stock of Soviet tanks at the eve of the war at more than 20,000, which is said to have been more than that of the rest of the world put together.² However, most of these tanks were, by that time, obsolete (BT series, T-28, and T-26). The modern T-34 and KV tanks were just entering mass production.

EARLY DESTRUCTION OF SOVIET ARMOR

The initial German attacks on the Soviet Union in June 1941 destroyed great quantities of Soviet armor. By the end of 1941, the tank strength of the Soviet "active army" in the West was claimed by the official Soviet war history to be down to about 1300.³ This disastrous loss was due to a number of causes: the surprise of the German attack, the general lack of preparedness of the Soviet Army, and the maldistribution of forces along the borders; the technical obsolescence of the bulk of the Soviet forces; the lack of repair of much of the equipment that was available;⁴ and, to a large extent, to the disorganization of tank forces and mistakes in their tactical use. All of

¹Lest it be thought that Stalin's interventions were always on the side of increased production and always beneficial, the memoirs of the wartime armaments minister, B. Vannikov, provide illuminating exceptions. For example, Stalin wanted to replace the 76-mm tank gun with a 107-mm field gun. Production of the 45-mm and 76-mm guns was actually halted at one point "with grave consequences for the Army." (Vannikov, p. 80.)

²Ogorkiewicz (1968), p. 35.

³IVOVSS, Vol. 3, p. 213.

⁴Only 27 percent of the old model tank park was in operating condition on June 15, 1941. (IVOVSS, Vol. 1, p. 475.)

these factors were exacerbated by the earlier purges of the top military leadership and officer corps. It was an ironic and near-fatal tragedy for the Soviet Union that the great amount of experimentation with equipment and tactics, and actual combat experience in the Far East, Spain, and Finland during the 1930s, had not produced an effective fighting force at the moment when it was most needed. Nevertheless, that earlier experience, reinforced during the initial campaigns against Germany, rapidly bore fruit. Hardware that had benefited from the previous decade of learning was already in production. Many of the incompetent (or just unlucky) military leaders were executed, including General D. G. Pavlov who had earlier reported to Stalin that the "lesson" of Spain had proved that "the tank can play no independent role on the battlefield." Pavlov had recommended that tank battalions be dispersed.⁵

ENHANCED PRODUCTION

The destruction of the bulk of Soviet armor, the requirements of the rejuvenated concepts for the mass use of tanks, the demands of Stalin for increased production, and the "objective requirements" of the war all combined to make production the prime objective. The number of tank types were reduced to the T-50, T-40, T-34, and KV. The T-50 and T-40 were discontinued after a short time and a simpler light reconnaissance tank, the T-60, replaced them. Commonality between models was encouraged--the T-34 and KV shared the same engine, gun, and many smaller components. The tanks were designed throughout to enhance producibility--for example, armor quality was reduced so that the "Duplex" process (instead of open hearth furnaces) could be used to increase production of plates and castings. Production technology was subject to continuous study and improvement. Design changes were kept to a minimum to avoid disrupting the flow of production. Despite the fact that several of the largest manufacturing plants in the western part of the USSR had to be evacuated to the east, production rates increased rapidly. During all of 1941, 6500 tanks were produced. In

⁵Clark, p. 36.

1942, the production rate was up to 25,000 armored vehicles of all types, and this rate was maintained until the war's end. For the battle over Berlin, the Soviet Union was able to amass 6000 tanks. Nearly 40,000 T-34 tanks were built through 1945, and the number of armored vehicles produced during World War II totaled more than 100,000.

The mix of vehicles that were produced underwent substantial change during the war years. Light-tank production, after initially high rates, gradually diminished in importance and finally ceased in 1944. The light tanks were not superior to the T-34 in cross-country mobility, and with their inferior armament and protection were considered to be useless for combat-support tasks. The T-70 light-tank chassis was subsequently used as the basis for the SU-76 self-propelled gun.

DESIGN AND PRODUCTION OF THE SELF-PROPELLED GUN

In October 1942, the State Defense Committee ordered the Commissariat of Armaments (which controlled artillery development and production) to design and produce a family of self-propelled guns within the shortest possible time. This was accomplished at the major tank plants by mixed teams of artillery and tank designers, with the tank designers usually assuming leadership positions. In remarkably short order, the chassis of the T-70, T-34, and KV tanks were converted to self-propelled guns. In 25 days, the heavy-tank designer, Kotin, had designed and built the prototype SU-152, which was based on the KV tank chassis and Model 1935 152-mm corps gun/howitzer.⁶ Within a few months of the 1942 directive, the first regiment of self-propelled guns was formed. Mostovenko notes that the speedy execution of this program was helped by the otherwise unfruitful prewar design experience. The cooperation of the artillery and tank commissariats was a feat that would seem possible only with a major war as an incentive.

The military planners' conversion to self-propelled guns was probably motivated by several factors. Tank production by late 1942 was solidly reestablished after the dislocation of industry caused by the

⁶Milsom, p. 131.

German invasion. Diversion of production could be tolerated at this point. Also, since these new Soviet weapons were assigned to the Armored Forces rather than to the Artillery, the tankists had less reason to oppose them. Perhaps, more important, was the demonstrated need for more mobile infantry fire support than that provided by Soviet field artillery and a need for heavier guns than those carried by tanks. The KV heavy tanks had been designed for breaching heavily fortified areas, but as the war progressed, attacks were planned to bypass such areas. The KVs were then used for infantry support and other, "standard" tank duties, but they were very expensive and had poor mobility. Self-propelled guns were cheaper than heavy tanks (as they did without the turret mechanisms and control systems); they were also lighter and more mobile, but carried equivalent or larger guns. The arrival of heavier German weapons in the Tigers, Panthers, and Ferdinands provided further motivation.

Following the initial directive, production of self-propelled guns accelerated rapidly until by the first 6 months of 1945 they constituted 40 percent of total armored vehicle production; by May 1945, they constituted 35 percent of total armor strength.⁷

The downward trend of light tanks and the rising trend of self-propelled guns during the war years is a measure of the general up-gunning of the armored-vehicle fighting force. This same trend toward increased firepower is also seen in the gradual replacement of the 76-mm guns on both the T-34 and KV series tanks. The T-34 ended the war with an 85-mm weapon, and the IS (Joseph Stalin) successor to the KV was equipped with a large 122-mm gun.

* * *

The Soviets' intense concentration on production during the war has had a continuing impact on the R&D process.⁸ Behavior, values, and

⁷ Mostovenko (1968), pp. 42-43; *IVOVSS*, Vol. 6, pp. 52, 207.

⁸ For examples in aviation, see Alexander (1970), pp. 31-33.

operating procedures consistent with mass production have continued to shape Soviet development activities in armor as well as in other weapons. This emphasis on high production rates, simplicity in design, and product improvement has been clearly evident since World War II.

VII. THE DEVELOPMENT OF SOVIET ARMOR, 1945 TO PRESENT:
CONSOLIDATION AND PRODUCT IMPROVEMENT

The tanks developed by the Soviet Union since the first appearance of the T-34 have been largely improvements of that basic design, although the cumulative change from 1939 to the appearance of the T-62 in the early 1960s has been substantial. A Soviet writer commented in 1975 that "the T-34 predetermined the development of tank building for a long time."¹ The main armament has been continuously upgraded, stimulated in large part by the firepower possessed by other countries. The original length of 30.5 calibers of the first T-34 models was increased to 41.2 calibers. Later models were equipped with an 85-mm gun. The T-54 and T-55 tanks carried a 100-mm gun, and the gun on the T-62 is a 115-mm smoothbore, high-velocity design. Muzzle velocity has increased from 2200 ft/sec to more than 5000 ft/sec.

MEDIUM-TANK EVOLUTION

An improved transmission appeared in later models of the T-34, and a new design was installed on the T-44. The T-44 also was fitted with a torsion bar suspension, this type having been used earlier on both the light and heavy tanks. The turret took on the carapace shape of the Stalin heavy tanks. The hull has been lengthened and widened somewhat, but the new turrets have reduced the already low silhouette. Most notably, the diesel engine is the same basic design that first appeared in a production vehicle more than 35 years ago. Output has been increased moderately from about 500 hp to approximately 580 hp (while the horsepower-per-ton ratio has fallen from 19 to 14.1). The transmission, drive train, and suspension system of the T-62 are like those on the T-44 of 1944. The track was changed on the T-54 and has remained very much the same since 1948. And except for the new 115-mm gun on the T-62, the guns have all appeared in other uses.² The 100-mm gun on the T-54

¹Yelshin, p. 28.

²A possible reason for the new gun on the T-62 is the high-velocity, fin-stabilized, discarding-sabot round that is used. This round is substantially different from previous ammunition, and attempts to fit it to

and T-55, for example, was first developed as a naval gun; it subsequently saw use as towed artillery, an antiaircraft gun, and an assault gun, before being installed on tanks.³

As mentioned above, a distinguishing characteristic of this 35-year tank series is simplicity. The range finder of the T-62 is of the simple stadiametric type; i.e., a silhouette of a standard object of known height is matched with the height of a target. The transmission is manual, and the steering is operated by two levers that change the gear ratio to each track--an improvement over the primitive clutch and brake system, but still rather uncomplicated. Mechanisms are rugged and are designed for easy manufacture.

Although simplicity, ruggedness, and well-proven design features increase reliability and reduce maintenance requirements, the tanks have not been specifically designed for easy maintenance. On the contrary, even simple maintenance on these tanks may require special equipment and many manhours.

HEAVY-TANK MODELS

In the heavy-tank-design class, the KV was improved throughout the war and gave rise to the Joseph Stalin (IS) series, the last model of which appeared in 1952. The next versions were the T-10 and T-10M, the latter being introduced in 1958. These models were only produced in limited numbers, the role of the heavy tank having been taken over by the modern, less-expensive medium tank whose high-velocity 115-mm gun is more effective than the bulky 122-mm weapon of the T-10.

LIGHT, AMPHIBIOUS TANKS

Light-tank design reached a dead end with the T-70, which was the last light tank to be produced in quantity during the war. After a lull of several years, the PT-76 began to be seen in large numbers in 1952. The PT-76 had no known predecessors and was said to be

an existing artillery tube could be very difficult or impossible. The requirement of a new gun design has retarded similar developments in the United States.

³Gooch, p. 18.

"fundamentally new."⁴ Lightly armed, thin-skinned, and amphibious, this tank was the main armored reconnaissance vehicle of the Soviet army for many years. Today it continues as the basis for a family of vehicles that includes a series of armored personnel carriers.

In the late 1960s and early 1970s, two new tanklike vehicles, the BMP and BMD, appeared and seem to have taken over the role of the light, amphibious, reconnaissance tank. The BMP is an amphibious, tracked, lightly armored, troop-carrying vehicle that houses a crew of three and eight infantrymen who can fire their automatic weapons through ports in the sides of the vehicle. The armament complement includes a 73-mm smoothbore gun, which fires a rocket-assisted projectile, and a Sagger antitank missile-launching rail. The Soviets describe the BMP as an "infantry combat vehicle," which implies a combination of troop-carrying and fighting capabilities. The troops inside the vehicle are protected against the effects of chemical, biological, and radiation hazards. The requirements for such an armored vehicle most likely grew out of shifts in strategic doctrine in the early 1960s toward the possibility of military action in a nuclear environment. The BMD is similar to the BMP, but it is lighter in weight, airborne, and air-droppable. Both of these vehicles represent significant departures from past development trends and philosophies.

PRODUCTION IN THE 1970s

Two tanks are known to be in production in the 1970s: the T-62, a direct descendant of the T-34, whose origins can be traced back to the American Christie M1931; and its predecessor, the T-55, whose current production appears to be intended for foreign export. The BMP and BMD infantry combat vehicles have taken over the role of the light, reconnaissance tank, and a new heavy tank has not appeared since 1958. A new medium tank was first observed during the Dvina exercises in 1970. It resembles the T-62 in several respects, particularly its turret and gun. Photographs and other sources indicate that several versions have been built, but at the time of this writing, there are no definite

⁴Yelshin, p. 30.

indications that either this vehicle or a modified version of it has gone into production.⁵

The main thrust of Soviet tank development in the postwar period has thus been the exploitation and improvement of the remarkable T-34-- a design that was created at the close of the 1930s.

⁵This vehicle (or vehicles) has been given several designations by different sources: M1970, T-64, T-72. Descriptions of the armament, engine, and other components also vary by source. These inconsistencies may indicate that an extended test program is being conducted to evaluate alternative configurations. (See, for example, *International Defense Review*, April 1975, p. 487.)

VIII. PATTERNS IN SOVIET MILITARY R&D

The Soviet weapons acquisition process exhibits many similarities across very different types of systems. Armor development shares many of the same attributes found, for example, in aircraft, ships, and missiles. The existence of these patterns suggests that a common set of forces operates across military services and technologies. These forces are identified here as arising, for the most part, from the centrally planned, seller-dominated Soviet economy.

SOVIET WEAPONS AND HOW THEY CHANGE

In general, Soviet weapons are relatively uncomplicated, with much emphasis placed on commonality of subsystems and standardization of parts. Several examples will be cited here to demonstrate the pervasive nature of this style.

Simplicity

One example is the SA-6 surface-to-air missile, which has been described as "unbelievably simple but effective."¹ Its solid-fuel engine is considered inferior to U.S. liquid-fuel designs under development, but it permits such simplifications as the elimination of a fuel control system.

Soviet warships require 25 to 40 percent less propulsion and auxiliary machinery per horsepower than U.S. ships, and proportionately less space in which to house it, largely because of a reduced need for the auxiliary machinery required for electrical power, fresh water distillation, and shipwide air conditioning. Moreover, the space allotted to personnel on Soviet ships is a third less per man, with a minimal amount allocated to administration, recreation and personnel services, such as the ship's store, laundry, dry cleaning plant, barber shop, post office, and exercise room. Since Soviet shipboard electronic equipment does not have the high-quality performance of similar U.S.

¹"U.S. Finds SA-6 To Be Simple, Effective," *Aviation Week & Space Technology*, December 3, 1973, p. 22.

equipment, it consequently requires less internal ship volume, electrical power, and other supportive elements. For these reasons and others, Soviet warships are smaller than their U.S. counterparts and yet carry greater armament.²

Soviet naval and ground radar systems exhibit lower performance than U.S. radars of comparable vintage, but they are also less complex, more reliable, and more easily maintained and repaired. Soviet radars of recent vintage have greater performance and are much more complex than older models, but U.S. radars have also changed in the same way, thus maintaining the earlier relationship.

Complexity in Some Soviet Equipment

As discussed in Section I, there is an empirical relationship between complexity and what is technically feasible. If a country's level of technology is low in certain areas, the achievement of given levels of performance can lead to higher levels of complexity. Thus, when the Soviets attempt to push the state of the art relative to their capabilities, their equipment can become more complex than U.S. equipment.

An example of this phenomenon has been observed in some of the equipment on board Soviet ships. Egyptian military commanders have noted that most of the Soviet hardware in their inventory is rugged, serviceable, and performs as required, but an Egyptian senior naval officer on a Soviet destroyer claimed that the equipment was considerably more complicated to operate and required much more manpower than comparable equipment on Western ships with which he was familiar.³ Soviet designers try to avoid complexity by judiciously selecting performance levels well within the limits set by their technological capabilities, but when those choices are not made well or are not possible, they may run into the problems of complexity and unreliability more quickly than their Western counterparts.

²This paragraph is based on Kehoe, pp. 59-61.

³"An Unsatisfied Customer," *Aviation Week & Space Technology*, July 7, 1975, p. 7.

Subsystem Commonality

Commonality of subsystems across equipment of the same vintage, together with repeated use of the same subsystems in succeeding generations, is another outstanding feature of Soviet weapon design. The Soviets, it is reported, practice considerable standardization in the auxiliary equipment and propulsion plants used on their warships. Off-the-shelf mechanical and electrical equipment, electronics, and weapon systems contribute to the small size of Soviet ships by reducing the space and weight margins required for the uncertainties associated with concurrent development of subsystems.⁴

In aircraft, the same turboprop engine was used on the TU-20 (Bear) and AN-22; the former first flew in 1955 and the latter in 1965. Soviet scientists also adopted the standardization concept for spacecraft. This permitted "the same spacecraft shell or body, the same service systems, on-board equipment, control circuitry, and power-supply systems to be adapted to the various mission needs. Thus, it was possible for them to go quickly from one mission to another, retaining maximum design continuity between spacecraft applications and modifications."⁵

As with the spacecraft, the design of the first Soviet space rocket system was the very epitome of the use of proven, standardized systems. The propulsion unit, taken from the Soviet ICBM program, consisted of a central core surrounded by four large strap-on stages. The core and each of the strap-on stages carried four rocket engines--or twenty altogether. Thus, rather than develop larger engines, the Soviets chose to make multiple use of available and proven components.⁶ A reason given for this design choice was the unavailability of materials that would withstand the higher temperatures generated in a larger engine, and cooling systems that were not adequate to reduce the temperature to tolerable levels.⁷

⁴Kehoe, p. 60.

⁵Stoiko, p. 103.

⁶Ibid., p. 93.

⁷Vladimirov, p. 50.

Evolutionary Growth

Technological change and improved weapons in the Soviet Union primarily result from the process of cumulative product improvement and evolutionary growth. Those few weapons that are of an entirely new design are often built up from proven components. The all-new system, with newly developed subsystems, has been observed only rarely.

The MiG-21 fighter aircraft, first developed in the mid-1950s, has undergone continuous change in its engine, aerodynamics, armament, avionics, and structure. It has been improved from a simple, clear-weather interceptor to an all-weather fighter with ground-attack capabilities. Range, payload, and flying qualities have all been enhanced over a 20-year period.⁸

The Soviet SS-17 and SS-19 intercontinental ballistic missiles can be traced back through several generations to the period after World War II when German and Soviet scientists worked on extending the capability of the German V2 rockets. The new Soviet ballistic missile systems that entered their test phase in the early 1970s (SS-16 to SS-19) are good examples of the Soviet practice of not introducing all new subsystems in a single new system, but of making more constrained, incremental changes from one generation to another. In this group of four missiles, no single vehicle included all-new components.

In ships, similar patterns of evolutionary change have been noted. The Kildin missile ship was a conversion of the last four Kotlin destroyers, and the Krupnyj class missile ships were based on the hull and propulsion unit of a cancelled class of destroyers.⁹ Early Soviet activities leading to a missile-carrying submarine followed a similar trend. The last of the Z-class diesel torpedo submarines were modified in the mid-1950s to carry three short-range surface-launched missiles. Underwater launching, improved missiles, and nuclear propulsion followed in a stepwise

⁸For a detailed development history of the MiG-21, see "Two Decades of the 'Twenty-One'," *Air Enthusiast International*, May 1974, pp. 226-232.

⁹McCWire, p. 79.

sequence, but in this case Soviet technology did not permit a viable threat to the United States until delivery of the Y-class missile submarines in the late 1960s.¹⁰

Wholly New Designs

Evolutionary practices in Soviet weapons development are so common that the appearance of new designs with no known antecedents can cause considerable surprise. However, even in these systems, many of the subsystems are based on proven components. This was the case of the four-barrelled, 23-mm antiaircraft gun, the ZSU-23/4, which first appeared in 1965. This lightly armored, tracked vehicle carries an integral search-and-track radar and backup optical tracking system. It was said to have been particularly effective in the hands of Egyptian forces in the Arab-Israeli War of October 1973.¹¹ The vehicle's chassis is based on that of the PT-76 light tank of the early 1950s. The engine is a 6-cylinder version of the tank diesel engine developed in the mid-1930s, and the electronics are vacuum tube components of 1950s vintage. The guns are modifications of World War II models. There is little new about this weapon--*except its design as a system*. This is a good example of the dangers of confusing high performance with advanced technology. The former is sometimes possible without the latter--with creative design. However, in other instances (early Soviet missile submarines, for example), creative design and efficient development processes could not make up for the lack of adequate technology. (It is also true that high technology does not guarantee the creation of effective weapons, if the conditions and processes of choice are misguided.)

REASONS FOR R&D PATTERNS

The pattern of simplicity, commonality, and incremental change is in large part a successful response to the limitations and constraints of the centrally planned, seller-dominated Soviet economy. There is

¹⁰ Ibid., pp. 83-85.

¹¹ "New Soviet Weapons Unveiled in Mideast," *Aviation Week & Space Technology*, March 24, 1975, p. 15.

general agreement among analysts in both the Soviet Union and non-Soviet countries that "in no major branch of industry is the average level of Soviet technology in use even close to being on a par with the U.S. and Western Europe."¹²

This state of affairs is the result of a centrally administered economy that has no automatic mechanism for fostering technological progress. Missing in this economic system is the flexible, risk-taking, profit-making, competitive entrepreneur of the capitalist world. Instead, new products and production techniques must be deliberately planned and introduced by bureaucratized administrative bodies and central government commissions. Attempts to reform the system have only increased the regulatory constraints, made the managerial task more complex, and further bureaucratized the planning and management of innovation.

Economic reforms since 1965 have not changed the decades-old milieu in which Soviet economic activity takes place. The success of an enterprise continues to be measured by plan fulfillment. Supplies are allocated by plans drawn far in advance of actual need. Overly taut planning has led to a general shortage of materials, i.e., to a seller's market in which a buyer must either take the product offered or go without. Without the policing forces of competitive markets, supplies are uncertain and quality levels cannot be relied upon. Given the central role of planning, resources are not fungible; i.e., a simple money budget is not adequate to guarantee the availability of resources that have not been specifically planned and allocated in detail.

The style of weapons design and development can be seen as a partial response to dealing with the problems of the economic system. The unreliability of supply from the civilian sector imposes a reluctance on designers to ask for new components, or to go to suppliers with whom they have not dealt in the past. Supply problems create incentives to use previously developed components that may not be optimal from an overall design standpoint, but that can be counted on to perform to

¹²Schroeder, p. 346. Much of this paragraph is taken from Schroeder's excellent summary of technological progress in the Soviet Union.

known specifications and that are known to be available from proven suppliers. The rigidities of the planning process allow little flexibility in substituting one material or device for another, or in making reallocations within a given budget level. All of these conditions encourage a conservative evolutionary approach that minimizes the necessity for flexibility and reallocation.

In addition to the economic forces that have molded the patterns of Soviet military R&D, there are other elements of behavior and motivation that point in the same direction. First, a military doctrine that emphasizes quantity and the mass use of weapons is consonant with simplicity in design and low-cost procurement. Second, the relatively low skill levels of a large citizen army require reliable and uncomplicated equipment. Third, a history of technological capabilities that have, in general, lagged the West may have induced an approach to the design of new weapons that emphasizes an attempt to approximate a rival's new technology, but in a stop-gap, catch-up manner.

The World War II experience impressed this style of weapons development on a generation of planners, scientists, designers, and military commanders. Learned under Stalin, and embodied in the operating procedures formulated during the war, this approach continues to dominate Soviet attitudes. The demonstrated success of the process, marked by the absence of a crisis born of failure, has promoted a reliance on proven practices. That the military R&D process is perceived as a success can be discerned in the attempts to transfer elements of the process to the civilian economy.¹³ In fact, the process has worked well within the constraints of Soviet ideology and economic structure.

OTHER RESPONSES TO THE ENVIRONMENT

The uncertainty of supply and the rigidity in the planning system have led to several other organizational and procedural patterns in weapons development as the military sector has attempted to insulate itself from the vicissitudes of the civilian economy. Materials, equipment, and personnel priorities have given military designers and

¹³ See Schroeder, p. 353; Holloway, p. 18.

producers somewhat greater control over these essential items than is possessed by comparable civilian enterprises. Moreover, the military production ministries, and even individual plants, tend to concentrate as much industrial self-sufficiency within themselves as possible, thus reducing the need for reliance on outside establishments. But even with priorities and concentrated capacity, the system often breaks down and orders are late or deliveries are unobtainable. To deal with these problems, and to expedite military production generally, there is apparently a high-level Ministry of Defense group charged with coordinating production and other affairs between the defense and civilian sectors. The party organizations also have an official responsibility for dealing with bottlenecks, shortages, and other problems arising in defense development and procurement.¹⁴

A key role in Soviet military R&D has been given to the chief designer. Chief designers and their organizations are at the central node between research and product, user and developer. They supply a coordination and leadership made necessary by the lack of a responsive economy. The chief designer acts as a technological entrepreneur who takes on the duty of organizing the development effort. It is the chief designer who is identified with the success or failure of a project. With these responsibilities, designers possess a degree of autonomy uncommon in the Soviet Union. One aspect of this autonomy includes a capacity for prototype construction and command of test resources that is not found in the civilian sector.

The special position of Soviet weapons development--the flexibility, autonomy, and priority which it enjoys--must be understood in relative terms. While clearly more effective than civilian R&D, Soviet military R&D cannot entirely escape from the perversities and inefficiencies of the rest of the economy. The military sector can be isolated, buffered, and given priority over civilian demands, but such strategies are neither costless nor completely successful, because the military increasingly

¹⁴See Gallagher and Spielman, pp. 18-19; and Holloway, p. 5. This function is also performed in the civilian economy, but in a much different manner--by back-alley deals, trade, barter, and other unofficial transactions.

must depend on inputs from all sectors of the economy. The weapons development process, while relatively flexible and autonomous in the small, is often rigid and overconstrained when observed on a larger scale. The emphasis on design continuity, the employment stability of research institutes and design groups, the inability of new entrants to break into established fields, and the practices and procedures by which R&D is managed can lead to excessive conservatism.

Although the military market is one of the few markets in the Soviet Union where the buyer prevails, products coming out of this sector have had difficulty in competing commercially with Western products. This is most evident in aircraft, where even Soviet Bloc countries would like to choose non-Soviet products but find it difficult because of export restrictions and foreign-exchange problems.¹⁵

Given the many incentives toward technological conservatism, major, nonincremental change must often come from high-level political interventions in the R&D process. Examples of this are numerous, especially in the World War II memoir literature and personal histories of the Stalinist era, but the practice appears to continue. It has been argued that intervention may now be declining because of the greater complexity of modern military weapons decisions and the increasingly diffuse structure of priorities in the Soviet Union. The High Command have attacked the arbitrary and personal decisionmaking of Stalin and Khrushchev and have pressed for increased military influence.¹⁶ These very arguments by the military, however, would seem to confirm the wholesale involvement of political leadership in the weapons development process. In aviation, where the record is more complete than in other areas, the Party and the government have been the key forces behind the development of jet engines and the first generation of jet fighters, heavy helicopters, swept wings, and vertical and short takeoff and landing (V/STOL)

¹⁵ For details on Czechoslovakia and Yugoslavia, see "Czechs View Soviet vs. Western Transport," *Aviation Week & Space Technology*, January 13, 1969, pp. 67-79; see also "Soviets Continue Low-Key Export Effort," *Aviation Week & Space Technology*, May 29, 1967, pp. 157-165.

¹⁶ Holloway, pp. 18-19.

technology.¹⁷ There is evidence that the fruits of the V/STOL efforts are now appearing in a shipborne vertical takeoff fighter of Yakovlev design.¹⁸

IN SUMMARY

Soviet military R&D appears to be more effective than civilian R&D because of the many special arrangements that have evolved to buffer military affairs from the overconstrained civilian sector. These arrangements include project autonomy and flexibility; priority over resources; concentration of production capacity within the military sector; high-level government organs to expedite military production; authority granted to the chief designer; continuous high-level political attention and intervention; and a style of R&D that has been demonstrated to be successful in other national contexts and that makes especially good sense in the Soviet Union.¹⁹ Despite this favored position, Soviet military R&D must exist within the total Soviet system, and it is free from the perversities of that system only in a comparative sense. As one study on Soviet defense science has concluded, "the chronic tension between autonomy and control continues to characterize the regime's basic and anomalous perspective on the role of the scientist in Soviet economy. Viewed in this light, the position of the defense scientist is of a piece with his civilian counterpart."²⁰

¹⁷Alexander (1970), pp. 26-27.

¹⁸"Soviet Notebook," *International Defense Review*, June 1974, p. 285.

¹⁹See Alexander (1973) for a comparison of Soviet aircraft R&D with that in the U.S. and France.

²⁰Gallagher and Spielmann, p. 73.

IX. THE DEVELOPMENT OF U.S. ARMOR, 1918-1940: TIGHT BUDGETS, TIGHT MINDS

United States armor development since World War I has been both similar to and different from that of the Soviet Union. Organization, doctrine, and budgets were strikingly different in the two countries, yet in both, early experiment was followed by a wartime concentration on production and a more recent emphasis on product improvement and evolutionary growth. Nevertheless, despite an analytical and literary desire to present comparisons replete with ironical connections, the plainer truth is that armor development in both countries evolved out of quite distinct experiences and environments, and unique sets of possibilities. Choice was bounded by dissimilar national values and constraints.

Almost all of the 80,000 armored vehicles produced by the United States during World War II were developed in the late 1930s--the results of a process that began at the close of World War I a quarter century earlier. The development of tank technology during these years was closely interwoven with the organization of tank forces, doctrine, and personalities. It is therefore necessary to place tank development in a context that includes these other influences.

In a complex weapon whose value is determined by a large number of performance characteristics, it is generally not possible to increase the value of some characteristics without degrading others. The choice of performance values within the constraints imposed by technology, development resources, and production costs is the heart of the requirements process.¹ And requirements generation is the core of development. The easing of the technological constraints is the function of research and development and leads to what is generally known as technological

¹The term "requirement" as used by the military has undergone an important change of meaning since World War II. Originally it referred to quantities and production schedules, as it still does in industry. Military usage now emphasizes the quality or capability of equipment. This shift in meaning, from quantity to performance, perhaps reflects an underlying change in attitude toward the source of value in weapon systems and how that value is achieved--quantity being associated with production and quality with R&D.

advance. The requirements generation process--i.e., the evaluation and choice of performance goals--cannot take place efficiently in isolation. Doctrine, tactics, the state of technology, operational experience, budgets, and potential enemies must be assessed. The process cannot be unidirectional and work well. Not only must doctrine inform R&D, but technology should interact with the theoretical and actual use of weapons. In the 1920s and 1930s, the requirements process in tank development tended to be unidirectional: doctrine was enunciated as a theoretical exercise; specifications were drawn from doctrine; technology was asked to respond. Organizational forms, based on doctrine, reinforced the entire process.

Movement nevertheless occurred, albeit at a slow pace. The late 1930s were substantially different from the early 1920s. The catalysts for change were found in diverse places: individuals, new technologies, and experience.

ORGANIZATION

Broad characterizations of large organizations must be recognized as distorted images. Yet, despite their conglomerate nature and the vital role played by key individuals, it is often possible to describe organizational themes and trends. It is meaningful to generalize about "the infantry" and how it differs from "the cavalry." In what follows, I shall concentrate on broad themes that influenced outcomes, while at the same time taking note of countercurrents and the influence of individuals.

Tank Corps

The U.S. Tank Corps was first established in France in early 1918 as part of the American Expeditionary Force (A.E.F.) in time to participate in the closing offensives of World War I. This limited combat experience with tanks (compared with the several years of use, experimentation, and thought by Great Britain, France, and Germany) prevented the development of a large and stable cadre of knowledgeable professionals. American organization and doctrine tended to be imitative

rather than innovative during much of the interwar period.² In a major reorganization of the Army after the war, Secretary of War Newton Baker and Chief of Staff General Peyton March requested independent status for the Tank Corps. Opposing this was John J. Pershing, the popular Commanding General of the A.E.F., who recommended that tanks become an adjunct to the infantry. In 1919, Pershing had organized a number of Superior Boards to consider the lessons of the war. These boards unanimously recommended that "tanks should be recognized as infantry supporting and accompanying weapons and be organized for association with and combat as part of an infantry command."³ Pershing's great influence with Congress and March's total disregard for and bluntness toward politicians contributed to the adoption of Pershing's advice.⁴

The National Defense Act of 1920 abolished the Tank Corps and formally assigned all tanks to the infantry, where they were to remain for the next 20 years. This legislated emasculation of their potential competitor was actively sought by the infantry, according to some observers, to prevent the emergence of an independent mechanized force comparable to the new air arm.⁵ Others, however, saw it as based on the near unanimous belief, held by tankers as well as by infantry leaders, that infantry was the "Queen of Battle" and that the role of tanks was properly to aid the infantry.

Two other reasons for the dissolution of the Tank Corps should also be cited. Antimilitary feeling of the period feared the establishment of a powerful strike force during peacetime. Pershing reflected these beliefs during hearings on the Defense Act. "The existence of such a great armed force would be militarism of a pronounced and objectionable type."⁶ Another objection to the establishment of a new combat arm was based on costs. Several Congressmen commented on the large fixed costs and overhead associated with any organization. It

² See Miller, p. 109; Hofmann (1973), p. 20.

³ Hofmann (1973), p. 21.

⁴ Ibid.; O. Nelson, p. 279.

⁵ Green, Thomson, and Roots, p. 189.

⁶ Quoted by Hofmann (1973), p. 23.

was better, they thought, to save these costs by placing tanks under an established branch.

Early Mechanized Units

The dispersal of the fledgling Tank Corps, its officers and men, its experience and enthusiasm, and its park of vehicles effectively consigned tanks to secondary importance in the interwar peacetime army. The inventory of approximately 1100 vehicles, which included more than 900 French designed Renault FT light tanks (M1917) of American manufacture and 100 British designed and American made Mark VIII heavy tanks, was assigned to 7 tank companies and 2 regiments spread throughout the infantry.⁷

The first reappearance of tank units combined into a large force was due to the influence of an individual who was not a party to the earlier decisions. In 1927, the Secretary of War, Dwight Davis, witnessed maneuvers of the British Experimental Mechanized Force. Impressed by this exhibition, he ordered the organization of a similar experimental American unit. In order to function as a military laboratory, Davis authorized the commanding officer to ignore existing regulations concerning organization, armament, and equipment.⁸ This unit operated during the summer of 1928, using the leftover wartime equipment, after which time it disbanded. In parallel to the planning for the experimental unit, the Secretary of War requested a plan for a long-range mechanization program. Appointed to the planning board was Major Adna Chaffee, Jr., a recent convert to tanks who, until his death in 1941, was a passionate and leading American advocate of mechanization. Before 1927, Chaffee knew nothing about tanks; after witnessing demonstrations of some experimental models, he became convinced that tanks would constitute the principal arm of a new and powerful force.⁹

In late 1928, a new Mechanization Board called for the permanent establishment of an experimental tank unit and an invigorated tank

⁷Ogorkiewicz (1960), p. 190.

⁸Nenninger, p. 85.

⁹Ibid., pp. 91-92.

program. All the branch chiefs, except the Chief of Infantry, General Stephen Fuqua, concurred in the report. Fuqua protested:

The tendency in this study to set up another branch of the service with the tank as its nucleus is heartily opposed. It is as unsound as was the attempt by the Air Corps to separate itself from the rest of the Army. The tank is a weapon and as such it is an auxiliary to the Infantryman, as is every other arm or weapon that exists.... Use of a mechanized force as a laboratory conflicts with War Department provisions outlining duties of the chiefs of combatant branches.... This would retard weapons development. Combat arms would have weapons thrust upon them which they did not develop themselves and which might be unsuitable.¹⁰

Despite this protest, plans for a mechanized force of 6 divisions were drawn up in 1929, but budget limitations (the proposed force would have cost an estimated \$270 million) and real uncertainties about the equipment and performance of large mechanized units limited developments to extremely modest efforts. A Mechanized Force with a handful of tanks and 600 men was officially organized in November 1930; 11 obsolete Renault light tanks, and 4 new T1 tanks made up the bulk of the equipment. This force operated for 7 months, when the new Chief of Staff, General Douglas MacArthur, disbanded it and directed all branches, especially the cavalry, to mechanize insofar as possible.¹¹

Expanded Use of Tanks

Largely a personal decision, MacArthur issued a memorandum on May 1, 1931 that would serve as a guide for the Army's mechanization until the beginning of World War II.¹² Entitled "General Principles To Govern Mechanization and Modernization Throughout the Army," it attempted to open and expand the concepts and theories concerning the use of tanks. It noted that tanks had many potential missions; to confine their

¹⁰Quoted in Nenninger, pp. 95-96. General Fuqua was partly reflecting the prewar experience of combat arms that were often forced to accept weapons in whose development they had no voice or influence.

¹¹Ibid., p. 106.

¹²Miller, p. 128.

development to one branch or to one use would unnecessarily restrict their future application. Drawing on earlier military experience, MacArthur pointed out that "Too often in the past, organization has been attempted from the standpoint of equipment rather than from the standpoint of mission assigned."¹³ He then attempted to break the infantry's domination over equipment and doctrine. As tanks gained strategic mobility, he observed, they would appear in organizations having missions beyond those normally assigned to the infantry. Tanks could also be expected to replace horses as the cavalry's principal means of mobility in combat. To ensure this development, MacArthur ordered the Mechanized Force of 1930 reorganized as a mechanized cavalry regiment. Since the National Defense Act had assigned tanks exclusively to the infantry, the term "combat cars" was assigned to those tanks operating with the cavalry.

Naturally, this plan aroused opposition--especially from potential losers under a new policy. The Chief of Infantry, General Fuqua, expressed strong disagreement to the extent of placing himself in the unusual position of supporting his traditional organizational rival, the horse cavalry. "Dehorsing cavalry regiments to form mechanized units would constitute an irretrievable loss to the Army."¹⁴

Given the limited budgets for development and procurement, and the rapid progress foreseen in tank technology, MacArthur advocated a strategy of gradualism. Experimentation, tactical tests, indoctrination, and preparation for production in time of emergency were the backbone of this strategy. As manpower levels and the War Department budget fell over the next several Depression years, MacArthur and successor chiefs of staff had little choice but to scale back their mechanization plans. The Army reverted to a skeleton combat force, which would have to depend on new equipment and new recruits to become effective in case of war.¹⁵

¹³ Ibid., p. 108.

¹⁴ Quoted in Nenninger, p. 111.

¹⁵ Pogue, p. 214.

Mechanization of the Cavalry

With its new responsibility as the lead branch in mechanization, the cavalry gradually overtook the infantry in the size of its tank force during the 1930s. It was helped by Chaffee, who had become chief of the General Staff section planning War Department budgets, a position from which he was able to lobby effectively for funds for cavalry tanks.

Fort Knox, Kentucky, became the home of the first mechanized cavalry detachment in late 1931. This detachment became a regiment the following year. A second regiment was formed in 1936. As funds for maneuvers became available in the post-Depression budgets, both regiments participated in maneuvers at Fort Knox and in larger-scale maneuvers elsewhere. One of the long-run benefits of the maneuvers was the education of officers from other regiments in the use of armor. However, the maneuvers reinforced a growing uneasiness about the large, clumsy combat organizations that had grown out of World War I. Field commanders strongly agreed with these views, which were shared by Chief of Staff Malin Craig.¹⁶

The Second Army maneuvers in 1936, the first real test of mechanized cavalry against a large mass of troops, emphasized the importance of flexibility in organization. By combining various elements as required during the maneuvers, it was possible to build up combat teams tailored to meet changing situations. By 1937 and 1938, the Army was committed to a smaller, more flexible tactical organization. This organizational flexibility became the hallmark of armored cavalry organization in World War II.¹⁷

By the late 1930s, it was becoming clear that responsibility for the development of tank units, tactics, and equipment was still too dispersed. While neither the cavalry nor the infantry wanted to relinquish control over tanks, neither branch would expand tank units at the expense of their traditional charges--horse cavalry and foot soldiers. In 1937, the Chief of Staff, General Craig, threatened that if the cavalry and infantry refused to view mechanization as an entirely

¹⁶ Miller, pp. 159-160.

¹⁷ Nenner, pp. 156-157; Ogorkiewicz (1960), pp. 92-93.

new force, and refused to permit it to develop in every possible way, he would "inaugurate a mechanized force without regard to arm of service in order to keep abreast of current developments."¹⁸ He ordered a new General Staff study on mechanization policies. This study produced a report in October 1937 that began, "Experience has shown that the older arms will fight in their traditional way.... Mechanization can be applied only through what it is in effect, if not in name, a new arm."¹⁹ These ideas were also being spread by the tank enthusiasts and by the gradual growth and demonstrated performance of the mechanized units themselves.

By 1938, the mechanized cavalry had grown to a full brigade and the War Department recommended a 3000-man mechanized cavalry division for experimentation purposes. Still, there was considerable caution--from the cavalry, Congress, and others--over the wisdom of such large-scale mechanized units. Emotional ties to the horse and the exceptional costs of mechanization were effective barriers to a new policy. Even after the German successes with their Panzer divisions in 1939, the Chief of Cavalry opposed expanding mechanized cavalry at the expense of horse units and the infantry rejected a General Staff proposal for converting its units into mechanized troops. However, both branches competed for any expansionary funds that might increase their overall strength.

In contrast to the views of the branch chiefs, commanders of the Field Armies were enthusiastic supporters of tank units and insisted on the participation of the armored cavalry brigade in the 1940 spring maneuvers in Louisiana. For the purpose of the maneuvers, the War Department organized a provisional mechanized division. The new medium tanks participated in the maneuvers and demonstrated a capacity that heretofore had been only theoretical. Following the maneuvers, and the continued German success in Europe, Chief of Staff George Marshall called a meeting of the Army's leading officers to finalize plans for organizing a separate armored force. On July 10, 1940 a directive was

¹⁸ Nenninger, p. 169.

¹⁹ Ibid., p. 170.

issued by the War Department stating, "For purpose of service test, an armored force is created."²⁰

DOCTRINE

Doctrine is often portrayed as a unified body of thought rather than as the patchwork assemblage it usually is. Formal or official statement of doctrine may be at variance with actual behavior. Furthermore, a one-to-one correspondence does not always exist between military doctrine and organization and between military doctrine and weapons. Doctrine can be broadly permissive of a range of possibilities. Nevertheless, doctrine had an important influence on the development of U.S. armor; the outcomes of the process were shaped by both the official and unofficial notions of how things ought to be.

When the United States entered World War I, Europeans found it "somewhat extraordinary that the American military services as a whole are unfamiliar even with the meaning of the term 'doctrine' when used in its purely military sense."²¹ Not to be outdone by their European peers, American military writers were quick to develop an American notion of doctrine as the application of science to the study of war. American methods of warmaking had been inefficient, said the military writers, because the American armed forces lacked unity of doctrine:

The object of military doctrine is to furnish a basis for prompt and harmonious conduct by the subordinate commanders of a large military force...without the necessity for referring each decision to superior authority before action is taken.... It is to provide a foundation for mutual understanding between the various commanders during hostile operations.²²

²⁰Ibid., p. 187. The wording of the directive was significant. "Armor" symbolized the break with both established infantry and cavalry traditions. "Service test" was used to circumvent the prohibition of the National Defense Act against the creation of a new branch without Congressional authority.

²¹This statement was actually made by an American naval officer, Lieutenant Commander Dudley W. Knox, who was explaining the "modern conceptions of war" to an American audience. (Quoted in Weigley, p. 511.)

²²Ibid.

This emphasis on approved policy and authorized methods may have been efficient in a period of primitive battlefield communications and stable technology of warfare, but it was dysfunctional in an era of rapid change. Nevertheless, the American military was concerned with survival in the face of severe budget stringencies in the 1920s and 1930s, and the military mood was to value and cling to basic essentials, including the principles governing the conduct of war.²³

Doctrine in the 1920s: Tanks Under the Infantry

The official doctrine concerning the role assigned to tanks depended heavily on the fact that the new weapons were assigned to the infantry as a subsidiary element. This doctrine closely followed the experience and wartime practice of 1918--which meant that tanks were intended to provide close support to the infantry. A formal policy on the use of tanks was issued by the Chief of Infantry in 1922. The first paragraph read:

The primary mission of the tank is to facilitate the uninterrupted advance of the rifleman in the attack. Its size, armament, speed and all the accessories for making it an offensive force must be approached with the above mission as the final objective to be obtained in development.²⁴

Despite the fact that tank technology and experience were still in their infancy, official doctrine, and its policing by the branch chiefs and others in high command, was inflexible and unyielding to new ideas or experimentation. The Chief of Ordnance, General Williams, noted in a speech on tanks in 1919 "that the military mind is a rigid one and does not lend itself to keeping pace with advanced technology and its impact on tactics."²⁵ When a conference at the General Services Schools at Fort Leavenworth in 1921 made recommendations that departed from established doctrine, the Adjutant General charged that instructors at

²³Ibid., p. 212.

²⁴Green et al., p. 190.

²⁵Quoted in Hofmann (1973), p. 22.

the conference made unauthorized assumptions regarding the tank service. "Uniformity of tactical doctrine cannot exist unless all schools base their teaching on existing organizations.... Any discussion of tank tactics has to begin with the premise that tanks serve as an auxiliary to the infantry."²⁶

In a similar vein, Eisenhower described his experiments with tanks at Camp Meade in 1919 and 1920. Commenting on the primitive nature of the vehicle, he thought that correcting its deficiencies "would require constant use in field maneuvers plus cooperation between military men and manufacturers. In those days, such cooperation was seldom thought of once the pressure of war was off. The use of the tank was, for the time being, turned over to the theoreticians."²⁷ When George Patton, Jr. joined Eisenhower at Camp Meade, the two young officers, taking advantage of Patton's experience in France and the fact that each was in command of a tank company, began a year of field experimentation in tactics combined with evening discussions of theory. The group of officers participating in these activities were aware that their developing ideas contravened official policy. "If some of the conservatives in the War Department had known exactly what we were up to, they might have condemned it as a waste of time for soldiers who might better be employed in close-order drill and road marches."²⁸ Eisenhower described how their ideas on equipment, tactics, and overall tank doctrine underwent continuous change with each day's trials. He especially seemed to value the opportunity for unconstrained activity, hidden away from higher-level scrutiny. "In one respect, these circumstances were better than battle itself. Trial and error and the testing of alternatives is experiment and research--but in action, you are offered few second chances."²⁹ Based on this experience, both Eisenhower and Patton came out from undercover and began to write articles for the military journals. Then Eisenhower was called before the Chief of Infantry.

²⁶Nenninger, p. 67.

²⁷Eisenhower, p. 156.

²⁸Ibid., p. 173.

²⁹Ibid.

"I was told that my ideas were not only wrong but dangerous and that henceforth I would keep them to myself. Particularly, I was not to publish anything incompatible with solid infantry doctrine. If I did, I would be hauled before a court-martial. George was given the same message."³⁰

The role of close support with the infantry, dictated for tanks in this period, was broadly permissive about the characteristics to be possessed by the weapons. The role really set minimum standards for speed, armor, and armament--enough of each to move with the infantry, protect it against machine guns, and knock out machine gun nests. More important, these tanks were to be distributed throughout the infantry, not concentrated in predominantly tank units.

Two other independent roles--breakthrough and exploitation--were urged by tank enthusiasts at the time, especially by the British theorists J.F.C. Fuller and B. H. Liddell Hart. These roles required more specialized tanks. Breakthrough vehicles had to be heavily protected and carry heavy guns. These ponderous vehicles had limited mobility and were expensive. For exploitation, speed, range, reliability, and cross-country mobility were important. Several British actions during World War I made use of the breakthrough concept in surprise mass assaults, the most prominent being the attack at Cambrai in November 1917 in which 474 tanks took part. However, the absence of infantry reserves prevented consolidation of the remarkable gains that were achieved, and the tank technology used at Cambrai was inadequate for a successful exploitation. Deficiencies in range and reliability, in particular, prohibited wide-ranging attacks on the enemy's rear, as called for by the theorists. Skeptics could point to these failings as evidence supporting a less-demanding role than that of independent breakthrough and exploitation.

The rigid, official view throughout the 1920s that infantry support was the only doctrinally acceptable role for tanks imposed severe constraints on tactical experimentation and technical development. This should have been a period of ambiguity, fluidity, and openness, rather

³⁰ Ibid.

than one of doctrinaire stances on issues about which few people at the time could possibly have had an informed understanding.

The Army's rigidity in this period was not confined to tanks alone, but was a more general characteristic of the interwar Army. George Marshall described the prevailing attitudes when he took over the infantry school at Fort Benning in 1927. Amidst "the even tenor of their theoretical ways," classroom battles were organized and predictable:

I found that the ordinary form of our tactical problems committed two deadly sins, relieving the student from the greatest difficulties of his tactical task in warfare of movement. The information of the enemy was about 80 percent too complete. And the requirement called for his decision at a pictured moment, when the real problem is usually *when* to make a decision and not what the decision should be.³¹

He found that officers "had been taught an absurd system, which proved futile the moment a normal situation of warfare of movement arose."³² Marshall sought to train his officers to "solve problems" rather than to memorize rules. "The art of war has no traffic with rules, for the infinitely varied circumstances and conditions of combat never produce exactly the same situation twice."³³ To acquaint the students with the latent possibilities of the newer technologies, Marshall had a special tank company established at Benning, but was balked in his attempt to get an air detachment.

Stimulated in part by the proddings of the Secretary of War, Congressional committees, and the dispersed tank enthusiasts, tank concepts and doctrine changed slowly. General Parker's 1928 report on mechanization asserted that tying tanks to the infantry reduced their mobility and shock effect. Tanks employed strictly as infantry support weapons were wasted. On the other hand, the Parker report considered entirely mechanized armies, as advocated by Fuller and Liddell Hart,

³¹Pogue, p. 251.

³²Ibid.

³³Weigley, p. 215.

inconceivable. Expense, logistical support, weather, and terrain ruled out such a possibility.³⁴ Parker recommended light tanks as the leading elements in the assault against weak points in the enemy defense. Self-propelled artillery and medium tanks supported the advance, and mechanized infantry would consolidate the ground. This report, as approved by the Secretary of War and supported by the conclusions of the Mechanization Board in late 1928, essentially reversed the former roles of tanks and infantry. Under this concept, infantry was to provide the tanks with close support.³⁵

Doctrine in the 1930s: Infantry vs. Cavalry

The Mechanized Force of 1930 was based on missions requiring tactical and strategic mobility and quick, hard-hitting power--with mobility emphasized. MacArthur's choice of cavalry as the leading branch in mechanization again emphasized mobility. The modern cavalry missions of reconnaissance, pursuit, and exploitation required cross-country mobility and speed of a high order. Infantry tanks, on the other hand, would depend more on armor and firepower than on mobility to accomplish their assault missions.³⁶

The Chief of Cavalry in 1930, General Guy Henry, welcomed the mechanization of his arm, writing that "combat cars" could replace horses "without changing the *essential mission* of the cavalry."³⁷ Significantly, Henry did not see cavalry as centered around horses, but rather as more broadly defined by a set of missions. This cavalry orientation toward mission rather than means permitted a smoother adaptation to change than was evidenced in other branches.

In 1933, the Chief of Infantry, General Edward Croft, expressed his agreement with the view that the development of highly mobile mechanized forces was best left to the cavalry. The infantry should concentrate on a less-mobile mission for tanks--in the traditional infantry

³⁴ Nenninger, p. 89.

³⁵ Ibid., pp. 93-94.

³⁶ Ibid., p. 109.

³⁷ Ibid., p. 211, emphasis added.

support role. "Personally, I doubt very much if in the next war tanks will be able to go charging about the battlefield in the face of anti-tank weapons no matter how hard we try to overcome inherent weaknesses."³⁸ The Infantry Board, to whom the above views were expressed, disagreed by pointing out the possibilities of independent tank actions in support of basic infantry objectives. Croft's ideas, however, prevailed and were fully supported and emphasized by his successors. This infantry view prevailed until the immediate pre-World War II period.³⁹

Meanwhile, during the 1930s, the cavalry continued to adapt the doctrine of horse cavalry to tanks. Its advantage over the infantry, as suggested above, lay in its broader conception of the cavalry role. This role went beyond horses. It had more to do with "cavalry traditions, *esprit*, and smartness," as the commander of the first armored cavalry regiment put it.⁴⁰ Or as Patton would say on many occasions, "it is the duty of cavalry and should be its pride to be bold and dashing."⁴¹ Chaffee summed up these sentiments with his aphorism, "the mission of cavalry is to fight." The essence of these concepts is in the breadth of what they permit, the open-ended nature of the possibilities. While not all cavalry officers were imbued with this openness of intellect, that branch seemed to have a greater number of such types than did the infantry.

Maneuvers with the armored cavalry regiment in the mid-1930s provided direct evidence for the development of doctrine. For example, questions about the competition and cooperation between horse and tank were investigated in the 1934 Fort Riley maneuvers. The need for attaching additional supporting units, such as engineers and motorized infantry, was also demonstrated, and organizational and tactical adjustments were made as a result of maneuvers in later years.

The commander of the mechanized cavalry, General Daniel Van Voorhis, summarized many of these organizational and tactical lessons to the Army

³⁸ Nenninger, p. 126.

³⁹ Ibid., pp. 127-128.

⁴⁰ Ibid., p. 139.

⁴¹ Blumenson, p. 852.

War College in 1937. In particular, he pointed out that as the mobility of units increased, difficulties in command and control became apparent. A solution to these problems was simplicity in organization without degrading the four tactical functions of mechanized cavalry--reconnaissance, fire support, defensive cover, and striking power. These functions could not be accomplished by tanks alone, but required a full combat team of combined arms.⁴² Other commanders were learning similar lessons from the maneuver experience. Above all, higher commanders were warned, it was important not to break up the tactical team of mechanized cavalry and its supporting elements. This concept of the combined-arms team would continue to dominate the thinking of those concerned with armor up to the present time.

Within the combined-arms team, however, tanks were increasingly viewed as the leading component. The most important doctrinal development of the late 1930s was the growing belief in the necessity of organizing a heavy, mechanized, striking force--a shock division. Chaffee, Van Voorhis, and an increasing number of officers on the General Staff and civilians in the War Department began to see the need for a tank division, supported by other components. The growing importance of individuals like General Van Voorhis with command experience in mechanized cavalry helped to push these concepts. As V Corps commander, Van Voorhis made several recommendations for expanding the mechanized brigade to division size in 1938 and 1939. However, the Chief of Cavalry at that time, General John Herr, ranked expansion of the mechanized brigade fourth out of a list of five priorities for expanding the cavalry. As late as the post-Korean War year of 1953, he contended that "one basic and immutable truth stands out through all our wars. Sometimes our commanders have to learn it the hard way: There is no substitute for [horse] cavalry."⁴³ Nevertheless, despite the continued attachment to the horse in the cavalry, War Department, and Congress, the concept of the mechanized force had clearly achieved a latent importance that the military crises of 1939 and 1940 would foster.

⁴²Nenninger, p. 163.

⁴³Ibid., p. 174.

BUDGETS AND CHOICES

The most important characteristic of armor R&D and procurement budgets during this period was their size--small. They were small partly because of overall budget limitations imposed by Congress on the Army, and partly because the available funds were allocated to other uses. First priorities were given to maintaining the strength of the officer, enlisted, and reserve forces.⁴⁴ Research and development received only 2 percent of the total Army budget in the typical year of 1937. Of that, the Air Corps got almost two-thirds and Ordnance was allocated 20 percent (\$1.35 million).⁴⁵ Tanks got less than 5 percent of the Ordnance R&D budget. From 1925 to 1939, the average sum allotted to tank development had fallen to \$60,000 per year.⁴⁶ This was enough to build or test one prototype and to work on a few other small projects.

Ordnance funds, in 1937, were divided into 21 major groups as shown in Table 1. The amount spent on artillery was ten times greater than that spent on tanks; even small arms received more funding than armor. Small arms had been the concern of Ordnance for over a hundred years, artillery for almost as long. A Caliber Board, constituted after World War I, had produced a fully articulated plan for artillery development that formed the basis of future activity. Tanks, however, were new to users and developers, had no plan for development, and were of secondary importance to the designated users. Therefore, R&D funds for tanks were certain to be given low priority.

It is easy to see that the relative penury under which tank R&D was expected to operate was not totally due to an overall lack of funds, but was more the result of explicit choice combined with complex organizational motives and processes. This is made clear from the development experience of the Christie tank, for which Congress appropriated money that was never spent.

⁴⁴Miller, p. 10.

⁴⁵Ibid., p. 201.

⁴⁶Green et al., p. 195.

Table 1

ORDNANCE R&D BUDGET ALLOCATIONS, 1937

<i>Budget Group</i>	<i>Budget Allocation</i>
Artillery ammunition	\$ 250,000
Artillery ammunition procurement for test	112,000
Mobile artillery	101,000
Ballistics research	77,000
Small arms	68,000
Railway artillery	65,000
Artillery fire control	64,000
Tanks	60,000
Miscellaneous 13 groups	553,000
Total	<u>\$1,350,000</u>

SOURCE: Green et al., p. 205.

THE CHRISTIE TANK CONTROVERSY

The American inventor, J. Walter Christie, whose M1931 prototype tank formed the basis for the development of Soviet armor, dealt unsuccessfully with the U.S. military from 1916 until 1942. His M1928 high-speed, convertible (wheel or track) tank chassis was offered to Ordnance for test in 1928.⁴⁷ Both the infantry and the cavalry were enthusiastic supporters of the design, and the Chief of Ordnance recommended to the Congress in December 1929 that \$250,000 appropriated for other tanks in the FY1931 budget be used to purchase several Christie tanks for service test. This was agreed to by Congress. But Christie was difficult to deal with and after prolonged negotiations, the order for cavalry vehicles was revoked early in 1930. New bids were then requested for an infantry version to which Christie responded, but his bid did not conform exactly to the mechanical specifications outlined by Ordnance. Meanwhile, a new Chief of Ordnance had been appointed who opposed buying more than one pilot model, saying that it was Department

⁴⁷The M1928, which was also referred to as the M1940 "because it was 10 years ahead of its time," was developed by Christie out of his own funds at a cost of \$382,000. The information on the Christie tank is taken from Hofmann (1975), unless otherwise indicated.

policy to buy additional models only if tests proved satisfactory and all defects were corrected. Ordnance was also irritated that the combat arms had been given the opportunity to test the tank before Ordnance. When the Chief of Staff called a conference to resolve the conflict, the Chief of Ordnance complained that the infantry had neither the right nor the ability to comment on the technical characteristics of tank design. By the end of FY1931, \$188,000 of unobligated appropriations reverted to the Treasury and the prototype was returned to Christie.

The subject was brought before the next Congress, which again provided \$250,000 for FY1932, with a request to the Chief of Staff that the twice-expressed wishes of Congress be carried out. This time, 7 tanks, based on the M1931 model, were delivered--3 medium T3s for the infantry and 4 T1 combat cars for the cavalry.⁴⁸ For the FY1933 budget, \$200,000 was appropriated, but Christie was becoming even more upset over Ordnance's strict insistence on detailed specifications and refused to bid, stating "the specifications as prepared do not conform to the advanced art in the construction of tanks and contain requirements which this company could not and does not desire to comply with in view of the improvements already tested by it."⁴⁹

When the War Department refused his continuing offers to sell it the M1928 model tested earlier, and for which the original \$250,000 had been appropriated, Christie became incensed and parked the vehicle in the courtyard of the State, War, and Navy Building (now the Old Executive Office Building), where it remained for several months. Thus, the FY1933 \$200,000 went unspent on the Congressionally mandated items.

The failure of Ordnance to spend funds that were available can be laid to an overreliance on highly detailed specifications and an inflexible requirements process. George Patton, Jr., who was excited by the Christie designs and was involved in the cavalry side of the negotiations, illuminated the problem that confronted the Army: "The

⁴⁸The M1928 was a chassis only and not fully equipped as a tank. The M1931 was the tank based on the M1928 chassis.

⁴⁹Hofmann, p. 16.

reason for this state of uncertainty is due to the fact that in the Christie car we are buying a principle, not a vehicle.... Mechanical progress can only result from physical experiment."⁵⁰ The other source of difficulty was Christie's fiery temper and impetuous personality, which did not fit in with the highly structured Army approach to development. Several years later he said of these experiences: "All I want the Army authorities to do is say: 'Give him the money and let's see what kind of machine he can turn out'."⁵¹ It may be that Christie's concepts as developed in the Soviet Union and later in Great Britain were successful because the inventor was too far away to interfere; they gave him the money, took what he gave them, and progressed from physical experiment.

The Christie tank case raises the question of whether Congress could have been convinced by a more forthright Army that the tight interwar budgets were seriously impairing military development. Christie and his enthusiastic lobby were able to generate a response from the Appropriations Committee that military men could not duplicate. In fact, neither the Secretary of War nor the Chiefs of Ordnance betrayed public anxiety about the small military budgets in their appearances before Congress or in their annual reports. Quite the reverse was true. Year after year they avoided making any appraisal, or they announced that American weapons were as good as or better than those of any army in the world.⁵² This was not because these military men and their civilian leaders were blind to the true state of their impoverishment. Private correspondence among the military chiefs bluntly described the severe lag in development. For whatever reason, this lack of frankness with the holders of the military purse strings was perhaps a contributing element to the declining War Department budget.⁵³

⁵⁰ Blumenson, p. 931.

⁵¹ Hofmann, p. 17.

⁵² Green et al., p. 207.

⁵³ Miller, in his study of the Army during the interwar years, suggests several reasons for its failure to state its case. The Budget and Accounting Act of 1921 specifically forbade agencies from asking for extra money from Congress, and for the most part, officers proved

DEVELOPMENT

The conflicts over doctrine, changes in the organizational responsibility for tanks, tight overall budgets and their allocation to other than tank users, bureaucratic rigidities within Ordnance and the combat arms, the inefficient requirements process, and a fast-changing technology made the development of tanks in the interwar period a difficult task. Yet, in World War II, the weapons developed during those years dominated the battlefields, in quantity if not in quality. Much of the activity bearing directly on the war effort took place in the last few years of the 1930s, but their origins were established in earlier years.

Pre-World War I Development

There was no U.S. Army work on tank designs until the country declared war on Germany in April 1917. A few private firms, though, had experimented with armored vehicles based on commercial tractors and components. As is true of most new products in their very early stages of development, no product paradigm had established a superiority over alternative configurations, and many different vehicles were built and tested, first with private financing, and later with Army funds after the United States entered the war. Weight ranged from 3 tons to 50 tons. Steam, gasoline, and gasoline-electric power systems were tried. Tracked, wheeled, and wheel-track combinations were investigated. Novel attempts to solve the always present tradeoff dilemmas in design were seen. A good example of this last point was the skeleton tank. The goal in this design was to keep down weight without sacrificing trench-crossing ability. This latter problem had been solved by British designers with a long track arranged around a lozenge-shaped frame. The entire volume between the two tracks was

reluctant to contravene the Act. Miller also suggests that the budgeting system put a premium on stability. If some items were different from those of the year before, they were likely to be cut. There was also the "psychological effect of repression" that made the Army hesitate to push its case for fear of being rebuffed, which was not uncommon in the Congressional committees of the 1920s and 1930s. (Miller, pp. 36-37.)

protected by armor and formed the fighting and driving compartment, leading to vehicle weights of 30 to 40 tons. In the skeleton tank, the lozenge-shape was achieved in skeleton form by using ordinary iron pipes with standard plumbing connections. A boxlike fighting and engine compartment was suspended between the track frames. Hence, only this box required armor protection.⁵⁴ The weight of the skeleton tank was reduced to only 9 tons.

In order to get tanks into production as quickly as possible, arrangements were made to produce British and French models in the United States. The British model was an improved version of its heavy, combat-proven, trench-crossing tank, which carried a 12-man crew and weighed more than 40 tons. The United States planned to produce 1500 of these Mark VIII Anglo-American tanks with about 45 percent American content and 55 percent British. Another 1500 Mark VIII vehicles, of all-American construction, were begun, but only 100 were produced, the rest being cancelled at war's end.

The other foreign tank to be produced was based on the French Renault 6-ton FT (*faible tonnage* or light weight). Redesigned in the United States for mass production, 4440 of the 6-ton tanks, Model 1917, were ordered, and 950 vehicles were built before production was halted at the end of the war.

Two native American designs were developed and ordered into production, but both of these orders were cancelled after the Armistice. A Ford 3-ton, two-man, light tank, based as much as possible on standard automotive components, was built in 1918. More than 15,000 were ordered, but only 15 were built. A larger three-man version was also tested, with a provisional order of 1000 cancelled in 1919 after completion of tests on the prototype.⁵⁵

From 1920 to 1935, no more than 35 tanks would be built in the United States. The Mark VIII and M1917 would make up the bulk of the inventory, almost up to the eve of World War II. Yet progress was

⁵⁴Ellis and Chamberlain, in Crow (1970), p. 139.

⁵⁵Specifications on all U.S. tanks through 1931 can be found in Jones et al., Chapter 16.

made, though at a glacial pace. Technological change was by small increments, but it was cumulative.

Development in the 1920s

At the end of World War I, there was much confusion over the future of tank designs with the Tank Corps, Infantry, Ordnance, and General Staff pulling in different directions.⁵⁶ Ordnance emphasis on automotive quality, safety, versatility, and structural solidity was often in conflict with the wishes of the tankers.⁵⁷ Furthermore, as the party responsible for standardization of the equipment, Ordnance paid more attention to formal specifications than did the users, who were more often interested in just something that worked, although just what that "something" ought to be was contested by parties having conflicting interests.

This conflict of interest is illustrated by Christie's first tank, built in 1919 before the Tank Corps was abolished.⁵⁸ A Tank Corps committee that included Patton met with Christie to discuss the tankers' ideas as to what was necessary in a fighting machine. The vehicle that he delivered was based on these conversations, combined with his own ideas on mobility. It brought forth an enthusiastically favorable response from the committee. Patton wrote that this was "the first attempt in the field of...tanks where the entire machine and each component part thereof has been designed and constructed solely from the military standpoint."⁵⁹ Impressed with the Tank Corps enthusiasm, Ordnance prepared to award a contract to Christie, but before final approval was given they pointed out that several features and specifications failed to meet Ordnance standards. Patton replied that even though the Christie model failed to meet, exactly and rigidly, the

⁵⁶ Hofmann (1973), p. 22.

⁵⁷ Blumenson, p. 791; Green et al., p. 194.

⁵⁸ Christie's experience with the military is fruitful history for analysis because his perturbations of the system induced responses that outlined major and interesting features of tank design.

⁵⁹ Blumenson, p. 793.

specifications set by the Tank Corps itself, as well as that of the Ordnance Department, it was nevertheless worth pursuing. Once the machine was built, Patton advised, it could be improved and perfected. Only after the commander of the Tank Corps assured Ordnance that the Christie tank represented the best approach to tank development "quite apart from compliance with technical details," did Ordnance reluctantly sign a contract with Christie.⁶⁰ After a few years of testing, Ordnance reported that whatever merit there was in the convertible tank, the poor engineering and mechanical faults did not warrant continuation of the project. In July 1924, the Christie tank program was cancelled, at a total cost (according to Ordnance) of almost a million dollars.⁶¹

Two medium tanks of about 25 tons, the M1921 and M1922, were also developed at the instigation of the Tank Corps. These programs were dropped, however, in 1923, after the dissolution of the Tank Corps and the publication of the 1922 infantry policy on tanks. This policy (as described earlier) defined the mission of tanks as facilitating the advance of the rifleman in the attack. It also called for the development of two new types: a light tank not exceeding 5 tons to be transported by trucks; and a medium tank of less than 15 tons as constrained by highway bridges, railways, and pontoon bridges. Because of the limited funds and the cost of tanks, the 1922 policy directed that only pilot models be developed and that Ordnance be allowed great latitude in pilot tank development in cooperation with infantry.⁶²

Despite the appearance of freedom of action for Ordnance, it was, in fact, quite restricted. Because of the sums of money involved, most decisions required approval by the General Staff, and the new technical requirements, especially the 15-ton weight limit, meant scrapping the ongoing program and working within new, tight constraints.

The first attempt by Ordnance to meet the 15-ton limit was its M1924 design, but overspecification of the system precluded success. In addition to the 15-ton requirement, the specification called for

⁶⁰Ibid., p. 794.

⁶¹Ibid.

⁶²Green et al., p. 190.

inch-thick armor to provide protection against .50-caliber armor-piercing bullets, a four-man crew, a 57-mm gun plus a machine gun, and a speed of 12 mi/hr. Based on engineering studies of this design, it was generally agreed that "everyone familiar with the tank situation knows that an attempt to build a satisfactory tank within the 15-ton limit is a waste of funds."⁶³ In 1926, the General Staff agreed to shift emphasis to a 23-ton tank, but ordered work continued on the lighter type. It was not until 1930, however, that a 15-ton tank--the medium T1--was constructed.

Light tanks were ignored while Ordnance concentrated on its medium-tank projects. The infantry also neglected small tanks until later in the 1920s, although its specifications for a 5-ton tank were as over-constraining as those for the medium tank. As interest in light tanks revived, a $7\frac{1}{2}$ -ton T1 (light) was built in 1927, and improved versions followed over the next several years.⁶⁴

Problems arising from the setting of requirements independently of technological capabilities continued throughout the decade. In

⁶³Ibid., p. 198.

⁶⁴Tank nomenclature during this period is confusing. The "M year" series (e.g., M1917), which was used until the mid-1920s, simply took the year of manufacture as the model number. Around 1926, duplicate series of "T" designations were applied to test models of light tanks, medium tanks, and cavalry "combat cars." An "E" suffix indicated experimental derivatives or modified versions. Thus we find a T1 light tank in 1927, a T1 medium tank in 1926, and a T1 combat car derived from the Christie M1931, which was similar to the infantry's T3 medium tank. When a model was standardized for production, it was given an M designation. In some instances, the M number was the same as the T number, but this was not always the case. Until 1942, light and medium tanks were numbered in parallel, but this procedure was ended when the light tank that followed the M3 was called the M5 to avoid confusion with the M4 medium. Major modifications that are standardized receive an A suffix. For example, the M4A1 to M4A4 series all had different engines. The M4A3E2 was a special assault tank with heavy armor. To further confuse the subject, the combat car designations were later merged with the tank series. The M1 and M2 combat car became the M1A2 and M1A1 light tanks. Many tanks were also known by the names of renowned generals. Names associated with light tanks were Stuart (M3), Chaffee (M24), Walker Bulldog (M41), and Sheridan (M551). Medium tanks were called Lee and Grant (M3), Sherman (M4), Pershing (M26), and Patton (M46). The U.S. Army's new tank, the XM1, has been provisionally named for General Creighton Abrams.

1929, for example, an Ordnance official complained that progress had been greatly hampered by "making *perfection* in an experimental vehicle the criterion for its standardization and by too great a faith on the part of the non-technical people...that any difficulty can be overcome by research and development."⁶⁵

The 1920s, then, were marked by conflicts over tank doctrine, changes in organizational responsibility, tight budgets and low priority, bureaucratic rigidities, and an inefficient requirements process. Despite these many problems, design experience was gained through development and test of the M1921, M1922, and medium T1 in the 20- to 25-ton class, the 15-ton T2, the 13½-ton Christie M1919, and the 7½-ton light T1 and its successors. With the establishment of the cavalry as the locus for mechanization, interest would shift in the early 1930s back to Christie's designs, but with just slightly more success this time than in the previous decade.

Development in the 1930s

Both infantry and cavalry interests were shifting to light tanks in the early 1930s. Christie's M1931 weighed more than 10 tons, but its ability to travel on wheels at high speed gave it the strategic mobility of trucked or railroad-carried tanks, and its innovative suspension gave it tactical and cross-country mobility unrivaled by even the lightest tanks of the period. As mentioned earlier, Congress authorized funds to purchase several of the Christie tanks and in 1931 and 1932, four of these went to the infantry as the medium T3 and four went to cavalry as the combat car T1. Sixteen improved models (medium T4) were produced at the Rock Island Arsenal beginning in 1934, closing out the development of the Christie designs. Ordnance then concentrated on its own designs, which were considered to be more reliable, cheaper to produce commercially on a large scale, and to meet more closely the ever-changing requirements of infantry and cavalry.⁶⁶

With the assignment of tanks to cavalry, the slow speed emphasized by the infantry was considered a great handicap. Cavalry requirements

⁶⁵Green et al., p. 198.

⁶⁶Hofmann (1975), p. 17.

called for fast, light vehicles with somewhat greater range.⁶⁷ Models of 5, 6, and 7 tons were examined, and a 3-ton vehicle was also considered.⁶⁸ In searching for a faster tank--the light T1 series was considered outmoded--a British Vickers 6-ton design served as a source for many of the features to appear on the light T2 prototype that was built in 1933. A rotating turret converted the fixed-turret T2 into the combat car T5, standardized as the combat car M1. It went into production along with its sister model, the light-tank M2A2 (derived from the T2); 170 of the two types were built by 1937.

A series of improvements were made to enhance the value of this family of vehicles. Heavier armor, improved suspension, a rotating turret with a 37-mm gun, and synchromesh transmission led, by 1939, to the light M2A4. An order for 329 vehicles was placed with American Car and Foundry Co. in October 1939.⁶⁹

Analysis of the European situation in 1939, as combat began to intensify, suggested that the most urgent improvement to the M2A4 would be an increase in armor protection. As maximum thickness was brought up to 37 mm, the vehicle's weight increased to $13\frac{1}{2}$ tons. To reduce ground pressure on the tracks, a trailing idler wheel, as used on the combat car M2, was incorporated in place of a fixed idler to lengthen ground contact and improve stability. Despite the increase in weight, there was no appreciable loss in performance.

As M2A4 production ended, with 375 tanks finally coming off the line, the improved version went into production as the light tank M3. The M2A4 was a critical interface between the halting experimentation of the preceding 20 years and the mass production requirements of World War II. It helped instruct Ordnance and industry in the details of tank production and formed part of the first shipments to Great Britain under Lend-Lease. Some vehicles saw combat in the Pacific, and others

⁶⁷ Details of light-tank development are available in Ellis and Chamberlain (Number 4) and in Chamberlain and Ellis (1969).

⁶⁸ Green et al., p. 196.

⁶⁹ Ordnance believed at this time that only heavy-equipment producers, such as locomotive manufacturers, had the capability for manufacturing tanks.

were used for training in the United States and Great Britain. It was the progenitor of two light tanks, the M3 Stuart and the M5, which were produced in the tens of thousands, and its components were the foundation of the medium M2 and M3 tank programs. Thus, the most important American tanks in World War II could trace their origins to the T2 design of 1933.

With the revival of interest in small tanks in the 1930s, medium-tank development went through a hiatus of several years following the Christie-derived T3 and T4 program. A new medium tank, the T5, designed on more conventional lines was begun in 1937. For economy and standardization, the T5 used a layout similar to that of the existing M2 light tank and many of its components and features.⁷⁰ The T5 and the M2 had the same engine, suspension system, sprockets, and track and had similar transmissions. The T5 was built to a 15-ton weight limit, carried a 37-mm gun, and had machine guns placed for enfilade firing on trenches. The Continental air-cooled, radial, 7-cylinder, 250-hp aircraft engine proved to be too small for the 15-ton vehicle. A larger 9-cylinder, 350-hp Continental engine was installed. With a few other changes, which brought the weight up to 19 tons, the T5 was standardized as the M2. At the time of the German invasion of France in May 1940, the 18 M2 tanks (3 prototypes, 15 production items) were the only modern medium tanks in the U.S. Army.

In August 1940, General Chaffee, Chief of the month-old Armored Force met with Ordnance officials at Aberdeen Proving Ground. The main point of discussion was the urgent need for a tank with a 75-mm gun. Some of the German tanks in France had been armed with 75-mm guns, which made the upgrading of the 37-mm gun on the M2 a topic of paramount importance. The small turret of the M2A1 would not accept such a large gun, and since no turret of the required size had ever been built in the United States, it would have taken too long to develop a new one. An interim solution was sought to provide time for

⁷⁰Details on the development history of the M3 medium tank were taken primarily from Chamberlain and Ellis (Number 11) and from Chamberlain and Ellis (1969).

the design and development of a new turret. About a year earlier, the original T5 prototype had been modified to carry a 75-mm howitzer in a side sponson on a modified hull front.⁷¹ Developed as a feasibility test for mounting a self-propelled gun on a medium-tank chassis, the T5E2 proved out the configuration on which the M3 Grant was based. More than 6000 M3 tanks were built between 1940 and 1942.

⁷¹A "sponson" is a gun platform standing out from the side of a vehicle or ship.

X. THE DEVELOPMENT OF U.S. ARMOR, WORLD WAR II: TANKS IN MASS PRODUCTION

Armor development during World War II proceeded in three concurrent streams, each dependent on the other: (1) A rapid and tremendous buildup in manufacturing capacity followed by the largest production ever of tanks and other armored vehicles. (2) A constant improvement of the light- and medium-tank models available when war began, based on combat experience and an evolving technology. (3) Experimentation and development, based on new subsystems and advanced technology, stimulated the design of new models.

PRODUCTION

Beginning in mid-1940, production plans for tanks doubled and redoubled. Looking backward, the peak planned figures appear preposterous. At the time, even the first numbers put forward were hard to believe. In June 1940, production plans for light tanks called for 405, and the 18-month plan for medium tanks was for 1741. The German invasion of the Soviet Union in July 1941 brought forth a Presidential directive that tank production be expedited at once. Production plans were scaled up to 1000 medium tanks and 400 light tanks per month. When this schedule was told to President Roosevelt in mid-September, he was said to have paused, placed a cigarette in his holder, lit it, and demanded, "Double it!"¹

After the United States had joined the war, in January 1942, Roosevelt again raised the requirement, calling for annual production rates of 45,000 tanks in 1942 and 75,000 by 1943. For a country whose total tank production in the preceding 20 years was less than 1000, a 75,000-per-year goal was open to ridicule. According to one biographer, Roosevelt had promulgated these figures as a way to capture the imagination of the American people by giving them a great challenge. Some of the production figures proposed by Roosevelt had, in fact, been arbitrarily revised upward by him on the eve of their presentation.

¹Thomson and Mayo, p. 232.

When Harry Hopkins questioned the President on the figures, Roosevelt shrugged, "Oh--the production people can do it if they really try."²

The called-for number of tanks would have supplied 123 armored divisions with light tanks and 216 divisions with medium tanks, plus 100 percent replacement for a year's operation. The number of armored divisions actually organized throughout the war was 16.³ The realization of a peak production rate of 30,000 tanks in 1943 was due as much to the stimulation provided by the President as to the latent production capacity of the country.

When General Motors President, William S. Knudsen, came to Washington in the spring of 1940 as the industrial production expert of the National Defense Advisory Committee, he began looking over Ordnance tank production plans. With the buildup in production requirements planned in June, he concluded that the locomotive companies' one-at-a-time production methods were totally inadequate for the job, but that the assembly-line experience of the automobile industry could meet the demand. Ordnance agreed but saw great difficulty in converting the automobile plants to tank production. Knudsen proposed, instead, to build an entirely new plant as a tank arsenal in Detroit. On June 7 he called K. T. Keller, the President of Chrysler, who immediately put his production planners to work on the problem.

Since Chrysler had never made tanks, and most of its engineers had never even seen one, they went to Rock Island Arsenal to look at the M2A1 medium tank, and took home copies of the 186 pounds of blueprints. By July 17, initial construction plans were ready, and it was decided to produce the as yet undesignated derivative of the M2 with the 75-mm gun. Concurrently with the design and construction of the plant, the M3 design was under way. A contract was signed for Chrysler to produce the new tank in the new plant before either was complete. A Chrysler engineer was sent to Aberdeen where the M3 was being designed.

²Sherwood, p. 474. Stalin was also giving top priority to increased production at that time, and was trying to stimulate production by calling for seemingly impossible goals.

³Much of the story on wartime tank production is taken from Thomson and Mayo, Chapter 10.

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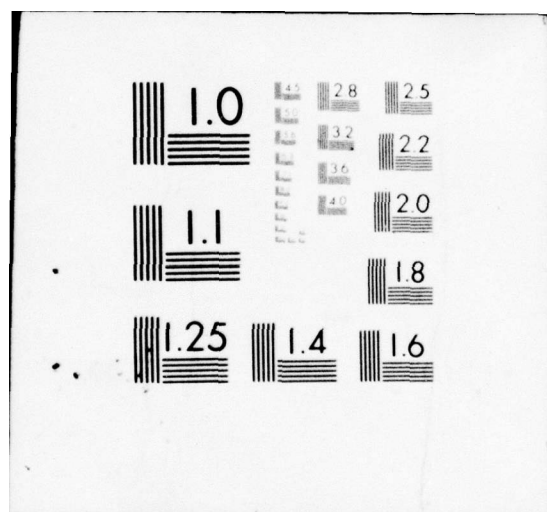
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He mailed the blueprints to Detroit, telephoned other information, and made suggestions to Ordnance designers on engineering changes that would mean cheaper and faster production.⁴

By late 1940, the steel skeleton was erected for the new arsenal, and the first tank rolled out in mid-April. In July 1941, the arsenal was gearing up to a production rate of 100 tanks per month. During 1942, it was enlarged to allow production of more than 700 per month.

Throughout the war, the Detroit Tank Arsenal produced 25 percent of the 88,400 tanks built from 1940 to the end of 1945. Seventeen facilities in all were in the production program, with the automobile and locomotive companies leading the list. The rapid buildup in productive capacity was not without its problems. Plants were built and never used. The balancing of subsystem production was always extremely difficult as bottlenecks affected engines, transmissions, guns, castings, etc.⁵ But by the middle of 1943, problems were well enough in hand and inventories were high enough so that 1944 production could be set 40 percent below that of 1943.⁶ Production rates in the spring of 1943 had reached about 4000 tanks per month, which was only about half of the total capacity that had been put in place at a cost of approximately \$250 million for tools, equipment, and buildings. Thus, within 2 years, American industry had tooled up to produce even more than the wildest of Roosevelt's demands, and had actually turned out tanks at a peak rate of more than 45,000 per year. As the requirements for quantity

⁴ Similar techniques are used in Soviet aviation to manage the transfer of a design from a design bureau to the manufacturing plant. See Alexander (1970), pp. 14-15.

⁵ An example of this problem was the transmission for the M4 medium tank (which followed the M3). Mack Manufacturing had completed only one transmission as the M4s began to come off the lines of three other contractors. This transmission was shipped to American Locomotive for a ceremony attended by the Under Secretary of War honoring the first M4. The transmission was then removed and shipped to Baldwin Locomotives for their ceremony. This same unit subsequently saw installations in several other vehicles.

⁶ The chief of the Ordnance Tank Division would say after the war, "If you do any research on procurement don't look at it as it was in 1944. Anybody could do it in 1944...go back and look at 1940-41 if you really want to learn something about procurement." (Quoted in Thomson and Mayo, p. x.)

were becoming satisfied, attention began to turn to efficiency, standardization, and improvements. The chief Ordnance officer for tanks commented on the production of M3 mediums in May 1942, "We are beginning to run into the motor car dealer's problem. Our customers, the fighting men, want only the latest model."⁷

ORGANIZATION AND DOCTRINE

The Armored Force was formed in 1940, at the same time as the blitzkrieg operations of the German Panzer divisions were beginning to show evidence of German superiority in tank organization and doctrine. As was seen in Section IX, one of the first lessons learned from the fighting was the need for a larger gun. However, the new organization was not able to formulate a complete and consistent theory of armored combat prior to its own entry into the war. The tactics and strategy were necessarily learned on the battlefield with the early M3 Grants and M4 Shermans.⁸

There was a continuous debate during the first year of the war over the autonomy of the Armored Force. A major reorganization in March 1942 created the Army Ground Forces in which the Armored Force was the equivalent of a Field Army. As such, it had greater autonomy than the traditional combat arms of infantry and cavalry, but the Armored Force was never given the independence, to which it aspired, of the Army Air Force. The growth of the Armored Force in relative strength and autonomy reached its peak in mid-1942, after which time the Army Ground Forces policy focused on the belief that Armor "should join the Army."⁹ While the Armored Force continued to have responsibility for tactical doctrine and equipment, it had to yield to higher commands in the distribution of tanks. By 1944, Armor was reduced to the level of the other arms; it amounted to little more than a Staff Advisory Board to Army Ground Forces. At this same time, tactical emphasis moved toward a close association of tanks with small groups

⁷ Thomson and Mayo, p. 253.

⁸ Brown, p. 22. For a discussion of the M3 and M4 tanks, see "Development of Medium Tanks," below.

⁹ Palmer, p. 405.

of men on foot. Though not a return to the doctrine existing before 1940, the balance shifted in that direction.¹⁰

One doctrinal point was strongly held by the Army Ground Forces (AGF) during most of the war: the primary role of the tank was for pursuit and exploitation. It was a misuse of the equipment to commit it to an antitank role. That task was better handled by field artillery, tank destroyer units, and close air support.¹¹ The AGF was therefore not interested in new tanks especially configured for anti-tank use. Complementing this doctrinal point, and its implications for tank development, were the lessons learned in combat experience--principally, the AGF's desire for reliable equipment with which the troops were familiar. Reliability and familiarity reduced the need for maintenance and training, and permitted a greater proportion of the available equipment to engage the enemy. Major changes in design were undesirable because they reduced the number of tanks coming off the production line. Heavier tanks were particularly disliked because they could not be transported in as great numbers on available ships and ground transporters, they were less mobile in pursuit, and they encouraged tank crews "to go gallivantin' off chasing enemy tanks."¹²

Another reason why the U.S. Army was reluctant to accept more heavily armored, better-armed tanks was that they did not meet heavier tanks in large-scale armored operations until late in the war. U.S. Armor had not yet been forced into a tank arms race as had the Soviets whose T-34s and KVs had encountered the German Tiger I, Tiger II, and Panthers carrying powerful 88-mm and 75-mm guns. This type of confrontation had led the Soviets to develop the T-34/85 and the Stalin series of heavy tanks.

DEVELOPMENT OF LIGHT TANKS

Light-tank development during the war was primarily a continuation of the M3 model. Almost 14,000 M3 tanks were produced in three

¹⁰ Ibid., p. 417.

¹¹ Thomson and Mayo, p. 300; Brown, p. 23; Ogorkiewicz (1960), p. 91.

¹² Army Ground Forces Commander, August 1942; quoted in Brown, p. 23.

models through August 1943. The final production variant, the M3A3, had an all-welded hull, with increased room for fuel and ammunition, and a well-shaped turret. Substitution of twin Cadillac automobile engines for the Continental aircraft engine, and the addition of an automobile hydramatic automatic transmission, converted the M3 into the M5, which went into production in early 1942.¹³ Maximum armor was increased from 51 mm to 67 mm, and the weight of the M5 was a ton heavier than the M3A3. Almost 9000 M5s and M5Als had been manufactured when production was halted in June 1944. This was the end of the light-tank line, which had begun in 1933 with the T2 and which owed many of its features to the British Vickers 6-ton tank. More than 23,000 tanks in this series were produced during the decade of its existence.

A new light-tank design, the T24, was started by Cadillac and Ordnance engineers in the spring of 1943; and by October, the first vehicle was completed.¹⁴ This model was intended to be an entirely new design incorporating the best features from earlier production and experimental models as well as the lessons learned from operational experience. Although it was called a completely new design, its features were not new. The engine and transmission were the Cadillac components of the M5. The layout was adapted from the T7, a development model that had not gone into production. The 75-mm gun was adapted from the heavy aircraft cannon used in the B-26 Mitchell bomber. The torsion bar suspension had been patented by the Ordnance project coordinator in the early 1930s. The turret ring was taken from the M5. The controlled differential steering system was patented in 1918 and had been used on American tanks since 1932. This "new" T24 vehicle was quickly standardized as the M24 Chaffee.

Another interesting feature of the M24 was the modular design of its chassis assembly. The power pack assembly included the engines,

¹³This vehicle was originally designated as the light-tank M4. However, the designation was changed to M5 to avoid confusion with the medium-tank M4.

¹⁴M24 development is described in Chamberlain and Ellis (1969) and in Icks (Number 46).

transmission, transfer case, fuel tank, and radiators. The power train assembly comprised the differential, final drive, and steering control. The third assembly was made up of the track, wheels, torsion bar system, and support rollers. These three assemblies were intended to be used in other vehicles that were to be designed around a common chassis.

Although M24s started coming off the assembly lines in the summer of 1944, and 4000 were produced by the end of the war, very few saw any significant action. The M24's first major combat experience came 5 years later in Korea, where it was the only United Nations armor available to face the North Korean T34/85s. The Korean War provided the impetus to upgrade the M24 to the M41 Walker Bulldog in 1951.

DEVELOPMENT OF MEDIUM TANKS

Development of the medium M3 tank from the M2 was based on an essentially proven design. This fact, more than anything else, made the concurrent design and production planning workable. The one new feature on the M3 was the sponson-mounted 75-mm gun. The design of this gun was based on the old French 75, adopted as a standard field gun by the U.S. Army in 1918. As modified for tank use, it became available just as the first tanks came off the production line. This gun was the M3's strength and weakness. It was the largest Allied tank gun available in 1941 and 1942, but because of its location in the tank, the vehicle's full silhouette was exposed whenever the gun was in use. The M3 was eventually produced with four different engines and three different hulls--riveted, welded, or cast. More than 6000 were manufactured.

These tanks were used in the Pacific until 1945. In this area they met little Japanese armor opposition, and their slow movement through jungle matched the original 1922 requirement of "facilitating the advance of the rifleman in the attack." However, the M3 had always been considered only an interim design, and work on its successor was begun even before the M3 design was completed.

In April 1941, five provisional medium-tank designs were shown to the Armored Force, which selected the simplest for development.¹⁵ The prototype T6 had the same chassis and layout as the M3. It had a cast hull and a rotating turret carrying the 75-mm gun. Later, a somewhat simplified and strengthened welded hull was substituted for the cast hull, and the model was standardized as the M4 Sherman. (The cast-hull model was designated as the M4A1.) Tanks in the M4 series were built in 11 different plants and in greater numbers than any other tank in history--more than 48,000 were built from July 1942 to June 1945. As originally designed, the engine was the same 9-cylinder radial engine installed in the earlier M2 and M3 tanks. Several other engines were also used, giving rise to a series of model numbers (M4A1 to M4A6). The most common model was the M4A3, which had a new Ford V-8 unit, the GAA, developed for Ordnance and authorized for production in January 1942. More than 11,400 M4A3s were produced. One derivative was the M4A3E2 assault tank ("Jumbo"). Additional armor was welded to the front of the tank to increase the thickness to 4 in. and a new turret carried 6 in. of armor. This tank weighed 42 tons compared with the M4A3's weight of 31 to 34 tons.

The fighting in North Africa convinced Ordnance engineers that a better gun was needed than the relatively low-muzzle-velocity model installed on the M3 and M4. The initial plan was governed by the self-imposed requirement to minimize the time to design, manufacture, and install the gun. It would therefore have to fit into the tank without major modifications to turret or mounts and must not require the development of new ammunition. The high-velocity design was accomplished by using a newly developed high-quality steel. The project was begun on August 20, 1942 and the completed gun was standardized on September 10. Eighty of the new 76-mm guns were produced in the next month for installation and test.¹⁶ The standard M4 turret proved too small, but in 1943, the larger turret of an experimental T23 medium tank,

¹⁵ Details on the development of the medium M4 are taken from Chamberlain and Ellis (1969) and from Chamberlain and Ellis (Number 29).

¹⁶ Green et al., pp. 326-327.

expressly designed for the 76-mm gun, was subsequently used on the up-gunned M4. This 76-mm gun, however, was not used until late 1944. The reason for this delay had to do with user doctrine and perceived needs, and revived some of the old conflicts between Ordnance and the combat commands over what was desirable in tanks, a point to which we will return below.

Other changes were made during the production run of the M4. A steeper, welded front provided better protection and was easier to manufacture. "Wet stowage" ammunition racks, whose outer casings were filled with water and glycerine, were installed on the M4s to reduce ammunition fires. Some M4s were fitted with a 105-mm howitzer for close artillery support, and more than 3000 of these howitzer-equipped vehicles were built. In late 1944, production vehicles were fitted with a new horizontal volute spring suspension (HVSS), tested experimentally on the T20 series of tanks (see below), replacing the original vertical volute spring suspension (VVSS) that was first developed for the T2 light tank in 1934.

In addition to the 48,000 M4 tanks that were built between 1942 and 1945, a number of other vehicles were designed around the M4 chassis. These included tank recovery vehicles, tractors, bulldozers, mobile assault bridges, mine exploders, mine excavators, self-propelled gun carriages, and assorted development and experimental vehicles. Large numbers of Shermans went to Great Britain and the Soviet Union. These tanks subsequently found their way into the inventory of at least twenty countries, and greatly modified M4 Shermans were used by the Israelis in the Arab-Israeli war of October 1973.

DEVELOPMENT OF HEAVY TANKS

The only heavy tank that the Americans standardized during the war was the M6--the first heavy tank to be built in the United States since the Mark VIII of 1918.¹⁷ German tank operations in Europe in 1939-1940 caused the U.S. infantry to review its requirements for heavy weapons,

¹⁷ The M26 Pershing was originally standardized as a heavy tank, but that designation was later changed to medium.

and in the spring of 1940, Ordnance was authorized to develop a 50-ton tank with a 3-in. (75-mm) weapon. An innovative design for the time, the heavy T1 tank prototype had a ballistically well-shaped cast hull and turret between 3 and 4 in. thick. A 925-hp, 9-cylinder Wright aircraft engine was necessary to propel the vehicle, which had increased in weight during development to 62 tons. The first prototype was rolled out the day after Pearl Harbor. One of the prototypes tested a new electrical transmission, which reappeared on the T20 series. Railroad type disc brakes were used, and the gun was stabilized and had power traverse.

Standardized as the M6, 40 tanks were built, but they never saw action. The AGF complained that the gun was not large enough to warrant the large size and limited mobility of the vehicles, and that too much shipping space was required. Nevertheless, the M6 design allowed many new features to be tested on a production vehicle: Its cast and welded armor, gyro-stabilizer, power traverse in the turret, HVSS suspension, hydramatic and electrical transmission, and track system were all used on later vehicles.¹⁸

The only other heavy-tank design was the T14. It was built at British request in 1943 and incorporated as many features as possible from the M4 and M6. Only two prototypes were built.

An interesting combination of tank and self-propelled gun was under construction at the close of the war. Using the chassis and automotive components of the T23, the T28 vehicle had 8-in. armor and carried a high-velocity 105-mm gun. Because the gun was set in the hull front, it had only limited traverse. It was protected by a mantlet of 12-in. armor. Although the vehicle weighed 95 tons, it was powered by an engine of only 410 hp. Only two of these vehicles were produced, and the project was cancelled in 1947. The designation in the meantime had been changed to the T95 gun-motor carriage.

DEVELOPMENT OF THE M26 PERSHING

When U.S. forces met the German response to the heavily armed Russian vehicles in 1944, the medium M4 (Sherman) was the best U.S.

¹⁸Icks (Number 32), p. 82.

tank available. On a tank-for-tank basis, the M4 was clearly inferior to all of the newer German weapons. The Allies received report after report that the M4 75-mm shells, and even the newer 76-mm shells, were bouncing off Panthers and Tigers at point-blank range, and that the M4 constantly faced destruction by the powerful German guns.¹⁹ The Americans resorted to the use of wide encircling movements against the enemy's flanks and rear, where the German tanks were more vulnerable. With supporting airpower, excellent logistics, adequate reserves, and overwhelming superiority of numbers, the Sherman was used as an instrument of spectacular advance and exploitation,²⁰ but often at the cost of heavy U.S. losses. When mud reduced the mobility of the narrow-tracked Shermans, or when weather precluded air support, U.S. tankers became virtually mutinous over the inability of their tanks to deal effectively with the German armor. By the Battle of the Bulge, the tankers demanded more powerful weapons and were supported in their demands by General Eisenhower and the General Staff.²¹ The response to these insistent new demands was the M26 Pershing--the first truly modern American tank.

The M26 Pershing grew out of the experience and shortcomings of the M4 (Sherman), which started into full production in the spring of 1942. Many of the operational deficiencies of the M4 and its predecessor, the M3 (Grant), had been discovered in combat in North Africa. At the same time, German tanks were seen at close hand; but, more important, the trend of the German weapons toward greater firepower and improved armor protection was becoming apparent. U.S. Army Ordnance and the Armored Force decided that a new series of tanks should take advantage of both the lessons learned in battle and the technical advances that had occurred since the late 1930s. This was an opportunity eagerly sought by the tank builders who had long wanted to design a tank without

¹⁹ Brown, pp. 24-26.

²⁰ Mayo, p. 322; Chamberlain and Ellis (Number 11), p. 76.

²¹ Mayo, pp. 330-338.

the constraints of past configurations and with a greater selection of subsystems than had been available in the past.²²

Given the technical fluidity and a wide range of possibilities, the tank builders chose a cautious experimental approach. To begin with, three guns and three transmissions were intended to be tested in all of the possible nine combinations. The guns were (1) the proven 75-mm gun of the Sherman, but with an automatic loader; (2) a new 76-mm high-velocity gun that was beginning development simultaneously with the new tanks; and (3) a powerful, older, 3-in. gun that had been mounted in the M6 heavy tank and a tank destroyer. The transmissions under consideration were the synchromesh gear box of the M4, a new Torqmatic automatic transmission, and an electrical transmission developed by General Electric that had been tried in the heavy M6 tank. All models used a slightly modified Ford V-8 engine that had become very popular with M4 troops.

During the design and construction of these nine tanks (designated the T20 series), the new 76-mm gun proved successful, and the other models were cancelled, except for one automatic loader 75-mm gun, which turned out to be mechanically unreliable.

Another subsystem tested in this series of tanks was the suspension system. A new horizontal volute spring suspension (HVSS) was tried out in combination with the new automatic transmission and also with the older M4 synchromesh transmission. The proven vertical volute spring suspension (VVSS) of the M4 was combined with the riskier electrical transmission. (See Table 2 for model designations and vehicle characteristics.) It was then decided to convert one of the HVSS chassis to carry a new torsion bar suspension that was just going into production on a self-propelled gun.

Tests of the T23 prototype incorporating the high-velocity 76-mm gun, electrical transmission, and old VVSS suspension were so promising that 250 tanks were ordered, with production beginning in October 1943. Service tests, however, concluded that the tank was unsatisfactory for combat use, a principal objection being the new requirement

²²The development history of the M26 follows Chamberlain and Ellis (1969); Icks (Number 32); and especially Hunnicutt.

Table 2
MAJOR CHARACTERISTICS DIFFERENTIATING MODELS IN THE T20 SERIES OF TANK DEVELOPMENT

Model	Completion Date (month/year)	Max. Armor Turret/Hull (in.)	Suspension	Transmission	Gun	Gun Length (calibers)	Max. Muzzle Velocity (ft/sec)	Combat Weight (lb)
T20	5/43	3.5/2.5	HVSS	Torqmatic	76 mm	52.0	2600	65,758
T20E3	7/43	3.5/2.5	Torsion bar	Torqmatic	76 mm	52.0	2600	67,500
T22	6/43	3.5/2.5	HVSS	Synchromesh	76 mm	52.0	2600	69,300
T22E1	8/43	3.5/2.5	HVSS	Synchromesh	75 mm ^a	37.5	2030	68,000
T23 (pilot)	1/43	3.5/2.5	WVSS	Electric	76 mm	52.0	2600	72,500
T23 (production)	11/43	3.5/3.0	WVSS	Electric	76 mm	52.0	2600	75,311
T23 (HVSS)	(?)	3.5/3.0	HVSS	Electric	76 mm	52.0	2600	82,000
T25	4/44	3.5/3.0	HVSS	Electric	90 mm	50.0	3350	84,210
T25E1	1/44	3.5/3.0	Torsion bar	Torqmatic	90 mm	50.0	3350	77,590
T23E3	8/44	3.5/3.0	Torsion bar	Electric	76 mm	52.0	2600	79,390
T26	10/44	4.0/4.0	Torsion bar	Electric	90 mm	50.0	3350	95,100
T26E1	3/44	4.0/4.0	Torsion bar	Torqmatic	90 mm	50.0	3350	87,350
T26E3 (M26)	11/44	4.0/4.0	Torsion bar	Torqmatic	90 mm	50.0	3350	92,355
T26E4	1/45	4.0/4.0	Torsion bar	Torqmatic	90 mm	70.0	3750	96,000
T26E5	6/45	7.5/6.0	Torsion bar	Torqmatic	90 mm	50.0	3350	102,300
T26E2 (M45)	7/45	5.0/4.0	Torsion bar	Torqmatic	105 mm ^b	22.5	1550	93,000

^a Automatic loader.

^b Howitzer.

for personnel trained in the operation of the electrical transmission. Several T23s were also built with the newer HVSS and torsion bar suspensions for purposes of comparison, but these models did not go into production because of a continued lack of interest in the electrical transmission.

Meanwhile, a larger, 90-mm gun was under development. Forty of the production T23 tanks were modified to carry this gun, and it was planned to make similar modifications to ten additional chassis that would carry heavier armor and torsion bar suspension.

However, the electrical transmission, especially when combined with the heavy armor, increased the weight of the first prototype beyond acceptable limits, and the transmission was replaced in remaining vehicles with the automatic Torqmatic transmission. Interest was now centered on the more heavily armored design as a result of the experience following the Allied invasion of Normandy, and a refined model of this tank equipped with the 90-mm gun, Torqmatic transmission, torsion bar suspension, and heavier armor went into production in November 1944 and was later standardized as the M26 Pershing.

Experimentation with the M26 series of tanks did not end with its standardization. A long-barrelled, high-velocity, 90-mm gun was tested as a counter to the new high-powered German guns. Twenty-five of these T26E4s were produced at the end of the war, but the long barrel and two-piece ammunition proved to be clumsy in use and production halted. (An improved version of this gun was tested several years later on the M26E1.)

A 105-mm howitzer was also mounted on a T26E1 chassis. Since the howitzer was considerably lighter than the 90-mm gun, turret armor was increased and an 8-in. gun shield was added. This assault tank was designated the M45, and 185 were produced by the end of 1945.

In the abstract, the development history of the M26 Pershing is a good example of an experiment intended to produce information about a complex system. Various combinations of three transmissions, three suspensions, and five guns were examined. Armor thickness, meanwhile, grew from a maximum hull thickness of 2.5 in. to 4.0 in. Even in the midst of the time pressures of war, the development process achieved

radical results in a conservative, sequential manner. This process depended on the independent development of subsystems and components, tested and evaluated in experimental vehicles. Plans were flexible as test results, technology, threat, and perceptions contributed new information and revised old values. The final configuration and content of the M26 could not have been predicted at the beginning of the program, even though the total span of time was only $2\frac{1}{2}$ years. Many of the subsystems that were tested in the T20 program, but that did not appear on the M26 Pershing, were used to product-improve the M4 Sherman. The HVSS suspension and 76-mm gun were two such examples. The success of the Pershing is confirmed by the fact that it has been the foundation for the postwar development of U.S. main battle tanks, and its derivatives will be the standard of comparison into the 1990s.

Despite the quite remarkable development, production, and deployment of a wholly new tank in less than 3 years, there was considerable criticism of the "failure" to put the Pershing (or equivalent) in the hands of the troops by D-Day, or the Battle of the Bulge, or indeed by the end of the war. Only the first 20 saw combat in the closing days of the war in Europe.²³

This outcome had its origins in organizational incentives and doctrine. The AGF, which included the Armored Force and the Tank Destroyer Command, did not view tanks as the primary weapon against armor. Antitank missions belonged to the half-tracked tank destroyers, gun motor carriages, and other mobile direct-fire guns. The AGF believed that putting a 90-mm gun on a tank would only encourage tank units to stalk other tanks. AGF commander, General Wesley McNair, vehemently opposed producing the T26. His answer to the new heavy German tanks was the M36 Jackson tank destroyer equipped with a 90-mm gun. There is good evidence, however, that McNair's objections did not hold up development of the T26, even though he would have liked to do

²³The controversy still goes on today. J. D. Brown's article in *Armor* (pp. 22-26) on World War II doctrine drew forth a number of letters and articles on all sides of the subject. (See Brown, Bailey, and the letters that followed in the March-April 1974, July-August 1974, and November-December 1974 issues of *Armor*.)

so.²⁴ His objections were overruled and development continued at an accelerated pace.

Of more importance was the absence of a requirement for a heavily armed and armored tank since the end of World War I. The one heavy tank that had been developed in 1940 (the M6) was cancelled when the Armored Force declared that there was no use for it. The Armored Force, which, by 1943, had evolved into primarily an advisory group and generator of requirements, preferred the 90-mm gun mounted on the M4 to a similarly armored vehicle in the T20 series. Their early opposition to the new tank seems to have hinged on the probable time it would take to put it into production compared with fitting a new turret on the proven Sherman.

The field commanders who were having to deal with enemy armor at first hand requested highest priority for the new tank; or, if that was not possible, they wanted the M4 equipped with a 90-mm gun or a 105-mm howitzer. What they did not want was more vehicles with the old 75-mm gun.

Ordnance wanted to produce a new tank that they knew to be clearly superior in performance to the Sherman--a prewar design of mixed ancestry and obsolete technology. Ordnance opposed arming the M4 with a 90-mm gun as clearly a second-best choice, and one that would probably eliminate production of their new tank. Retrospectively, the AGF complained that Ordnance could have gotten a new tank fielded earlier if time had not been wasted on the electrical transmission and heavy tank designs, which the AGF did not want from the beginning.²⁵

Faced by the opposition of AGF, Ordnance attempted to sell the new tank directly to the Armored Force, theater commanders, and, interestingly, the British. When these commanders repeated their requests to Chief of Staff George Marshall, he ordered the production of the M26

²⁴C. H. Bailey presents illuminating information on the timing of development events, objections to development, and requests for accelerating the program. His evidence indicates that the various parties held the views generally attributed to them, but that timing was critical for understanding whether those views affected outcomes. (See Bailey, pp. 26-29.)

²⁵Mayo, p. 338.

in December 1943. By the time the first 20 Pershings were sent to Europe for combat test a year later, the 75-mm Shermans were being regarded as deathtraps and General Eisenhower at Supreme Headquarters sent a personal cablegram to put the highest priority on getting the Pershings to the theater. By this time, however, it was too late. Tank doctrine of previous decades, combined with the accidents of history, prevented the M26 from effectively engaging in combat in World War II.²⁶

²⁶The "accidents of history" included the absence of the largest German tanks and antitank guns on the Western Front until late in the war, the widespread acceptance of the well-proven and ubiquitous Sherman despite its known faults, and the fact that after the North African Campaign the United States did not fight in "good tank country."

XI. THE DEVELOPMENT OF U.S. ARMOR, 1945-1975: EVOLUTION OF EQUIPMENT
AND REVOLUTION IN R&D STYLE

Since the end of World War II, there has been continuity in the deployment of U.S. tanks. But interwoven with this central tendency toward continuity, shifting patterns can be observed in the style of development. Product improvement, and the evolution of the M26 Pershing (developed at the close of the war), led to the M60 tank series, which will serve in the U.S. forces into the 1990s. Competing with this line of vehicles were several experimental tanks, built from the end of the war until the late 1950s. While none of them was deployed, they contributed to product improvement.

In the late 1950s, the Army adopted a style of weapons system development that had become fashionable in the other Services, primarily in the Air Force. This R&D strategy was built around a collection of notions: high-performance goals made possible by high technology; design and development of an integrated "system"; and simultaneous development of most subsystems to the same high levels of performance as those sought for the system as a whole. Program integration thus became a critical problem, and program management organizations were established to coordinate development. Since, it was claimed, these weapons were intended to meet imminent, serious threats, schedules were tight, and production and deployment were planned from the beginning of the program. Unfortunately, the Army tank programs managed in this way were tremendously expensive and, at best, only partially successful. As a result of this experience, the newest tank development, the XM1, moved away from this "weapons system" strategy and back toward the experimental programs of the earlier postwar period.

EVOLUTION OF POST-WORLD WAR II MODELS

At the end of World War II, three series of tanks were in production: the light M24, medium M4, and heavy (later, medium) M26. In the first years after the war, Ordnance formulated two policies: (1) to concentrate its budgets on the development of components, such as

engines and transmissions; and (2) to design and build new prototypes of the three size classes.

The T41 was a larger, re-engined version of the M24 light tank mounting an improved 76-mm gun. It was standardized in 1950 as the M41 Walker Bulldog. One expert has written that the M41 was the least successful of the immediate postwar designs because, at 26 tons, it was too heavy for many light-tank tasks and not quite powerful enough for a medium-tank combat role.¹ However, it remained in an active status for almost 20 years until it was replaced in the late 1960s by the M551 Sheridan. The M41 continues to be in service in a score of countries.

A series of heavy tank designs based on the T26E3 (M26) vehicle was initiated at the end of the war, but was not completed until later. The T32 carried an improved 90-mm gun and 200 mm (8 in.) of frontal armor. The T29 was given a 105-mm gun in a massive cast turret that increased the total weight to 69 tons. The T30 carried a 155-mm gun and weighed more than 72 tons. The T29 and T30 were essentially similar, except for the guns. This same chassis, a lengthened T26E3 hull with eight bogie wheels instead of six, was designated as the T34 when it was fitted with a 120-mm gun.² In 1951, the T34 evolved into the T43 by incorporating the new engine and transmission of the M46 medium (see below), an elliptically shaped cast turret and hull for anti-mine protection, and a 2-m-base optical rangefinder. This model entered production in 1954 as the M103 heavy tank and was used in limited numbers by the Marines.

Medium-tank development after the war centered on a new T42 design carrying a 90-mm gun. Weighing only 36 tons, it was 10 tons lighter than the M26 Pershing. The T42 was similar in layout to the light M41 and possessed many of the same features. It also carried a rangefinder mounted in two "ears" on either side of the turret. With the addition of an automatic transmission, it was considerably easier to drive than previous models, and the designers convincingly argued that crew size could be reduced to four. The mobility was poor, however, because the

¹Ogorkiewicz (1960), p. 203.

²Chamberlain and Ellis (1969), pp. 164-165.

tank was 10 tons heavier than the light M41 but used the same engine and transmission.

As an interim measure prior to completion of the T42, the M26 was improved with a new 810-hp Continental AV1790 engine and automatic cross-drive transmission. This was standardized in 1948 as the M46 Patton. The engine was a product of the postwar component development program, and the transmission was developed out of experience gained during the war with the hydramatic and Torqmatic drives used on various standard and experimental vehicles. The new drive train produced several hundred more horsepower in a more compact package than previous systems, as well as making the driving task considerably easier. Improved versions of the engine and transmission continue to power the M60 tank series.³

TANK DEVELOPMENT IN THE 1950s

At the outbreak of the Korean War in 1950, many of the T42 components were still being designed, with the turret in the most advanced state of development. This turret was mounted on the M46 to produce yet another interim model, and was rushed into production as the M47 to satisfy the demand for improved armor in Korea. (The T42 project was subsequently cancelled.) Since neither the turret nor its installation on the M46 hull had been tested prior to production, numerous problems delayed the project, and it was a year before finished M47s could be sent to the troops. However, since the hull and equipment of the new tank were largely unchanged, the uncertainties and troubles were confined to the turret.

Even before the M47 had been rushed into production. it had been decided to redesign the hull and turret along the lines of the M103 (T43) heavy tank, and the program was initiated in early 1951. The resulting tank was the M48 Patton. Most of the interior components remained unchanged from the earlier M46/M47 models, and the elliptical shape of the hull and turret were taken from the M103. But once again

³Postwar developments are sketched out in Williams; in Icks (Number 52); and in Icks (Number 24).

the tank was rushed into production for use in Korea and once again a rash of technical problems impeded deployment.⁴ Although production deliveries commenced in April 1952, a report by the Comptroller General noted that "Initial production vehicles were defective to such an extent that they were not acceptable even as training vehicles."⁵ Most of the vehicles were manufactured after the Korean War had ceased in mid-1953. The major defects of the M48 were corrected in the mid-1950s through redesign, and the M48 became the M48A2. Another change was an improved fuel-injection engine and greater fuel tankage. These modifications increased the range of the M48A2 from 70 mi to 160 mi (250 mi with external tanks).

Parallel to the programs leading to the M48, new light- and medium-tank designs were begun, but neither of these advanced, novel designs was developed past the prototype stage. The light T92 project was started in 1952 and the tank was rolling in 1956. It was air-transportable, but not amphibious, and carried a 76-mm gun, as did the M41, which it would replace if successful. The gun was equipped with an automatic loader, which permitted a crew of only three. The tank mounted a novel "cleft" turret that had a large aperture extending from its front to its rear so that the gun and breech could move up through it. Because the turret did not have to accommodate the raised gun breech when the barrel was depressed, it could be considerably lower than a conventional turret. This turret, however, introduced additional problems and complexities, for example, the problem of watertight fitting. The tank also had a new rubber-in-torsion suspension and steel-cable-reinforced rubber belt tracks.⁶ The T92 was cancelled when requirements were changed to include amphibious capabilities.

The medium T95 had as many innovations as the T92.⁷ The most striking feature of this comparatively lightweight, 41-ton vehicle was a smoothbore, hypervelocity, 90-mm gun that fired a fin-stabilized

⁴The M46, M47, and M48 were all nicknamed "Patton."

⁵Icks (Number 24).

⁶Ogorkiewicz (1968), pp. 76, 80, 99, 103.

⁷See Shiovitz for a detailed description of the T95 program.

projectile.⁸ In one version, the gun was mounted solidly without recoil to test whether the complexity, cost, and weight of the recoil mechanism could be dispensed with. (It could not.) Altogether, five turrets and guns were tested on the T95, including a larger 105-mm smoothbore gun and a 105-mm rifled gun in an M48 turret that later appeared on the M60. The T95 had a low silhouette and the first flat-track suspension (no return rollers) seen on a U.S. tank since the Christie T4. The program was cancelled in 1960. One of the chief reasons for not standardizing the vehicle was that the cost of a complete retooling would have required more funds than could have been justified when compared with a simpler product improvement of the M48. The total program cost of the T95, including construction of the 11 vehicles, development of a simplified cross-drive transmission, and development of the smoothbore gun, was \$25 million.⁹ Comparison with projects to come later would show this experimental development to be a bargain.

While the T95 was undergoing final test, several guns were evaluated for possible use on a product-improved M48. These included the 90-mm high-velocity, smoothbore gun from the T95; a 105-mm gun of British origin designed to fire the new discarding sabot, hypervelocity British ammunition; an American redesign of the British 105-mm gun; and a larger 120-mm gun. For comparison purposes, both the 90-mm gun already mounted on the M48 and the 120-mm gun of the M103 heavy tank were included in the tests. The British gun showed marginal superiority over all the candidates, and it was recommended that it be considered the most suitable. However, it was subsequently decided to adopt the U.S. version of the British 105-mm gun instead.¹⁰

⁸The Soviet Union was also working on a similar 115-mm gun, which later appeared on the T-62.

⁹This figure was obtained from officials at the Tank-Automotive Command. A different source places the figure at \$18 million. (See United States, Senate, *Hearings...*, March 1974, p. 3479.)

¹⁰The following paragraphs on the M60 are based on: *Development of 105-mm Gun Main Battle Tank, M60 Series*. The tubes of the British and American guns were interchangeable; the major difference was in the breechblocks.

A few years earlier, a dieselized model of the gasoline engine used in the M48 had become available as part of the ongoing component development program and this engine was tested in an M48A2 in 1957. The engine demonstrated a more than 60 percent improvement in fuel economy over its gasoline-fueled counterpart. It was subsequently used in the up-gunned M48. With the addition of several other new components, the M48A2 tank was standardized as the M60 in April 1959. Because no complete pilot model had been tested prior to standardization, that action was subjected to review should difficulties arise. A year later, the Chief of Staff established a task force to correct some deficiencies discovered in the M60, and by 1961, most of the troubles had been eliminated.

TANK DEVELOPMENT IN THE 1960s

A new turret, added to the M60 in 1961, gave rise to the M60A1. With an elongated shape, it provided armor protection in the turret equivalent to that of the hull.

At the time that the M60 went into development, a three-country conference (the United States, Canada, and United Kingdom) agreed that the heavy-tank role had become too expensive to retain and that a new generation of shaped charge antitank weapons had rendered the heavily armored vehicle relatively vulnerable. It was decided to concentrate henceforth on medium tanks.

When the T92 light tank was cancelled in 1958, plans were drawn up for the M551 Sheridan, which was intended to be both air-droppable and amphibious.¹¹ This project was notable for two reasons: The Sheridan was the first tank to use a guided missile, and it was the first Army tank program managed as a production-oriented weapons system development under a program manager. The missile was the Shillelagh, and it was launched from a hybrid system that also fired 152-mm conventional ammunition. This gun/missile launcher system was later adapted to the M60A2 and the MBT70 (see below). The program-management strategy

¹¹In the official nomenclature, the Sheridan is not designated as a tank but as an AR/AAV, i.e., an armored reconnaissance airborne assault vehicle.

also spread to other systems, with the same results as those of the Sheridan--unpredictably high development and production costs, extended times to deployment, and considerable (often unmanageable) technical problems.

In 1964, an Army plan was approved to mount the gun/missile system on the M60, pending delivery of the just-begun MBT70. The first pilot vehicle, the M60A1E2, was completed in September 1965. The conventional round of the 152-mm gun/launcher system was, in fact, unconventional. The cartridge case was combustible, thus requiring no ejection or disposition. The turret also had a high degree of stabilization. Mating the new turret with the M60 hull proved to be much more difficult than expected, and extensive redesign was required. The combustible cartridge case was also extremely troublesome.

In 1966, considerable controversy arose within the Army over whether the guided-missile-firing M60 should be given limited production status. The Army Materiel Command (which was responsible for procurement) and user commands requested that a decision be delayed. The Army's Office of Research and Development recommended full production. Funding aspects of the program were considered of primary importance. For example, a memorandum within the Office of Research and Development supported the production decision by noting that Army support

1. Assures uninterrupted continuation of the program.
2. Voids the likelihood of FY1967 funds being denied at May 1966 apportionment.
3. Better assures meeting the urgent military requirement objectives of the program.
4. Does not unnecessarily focus OSD/BOB [Office of Secretary of Defense/Bureau of Budget] attention on the program.
5. Does not place the entire program in jeopardy of premature cancellation by OSD/BOB.¹²

The memorandum went on to say that delay would place "an element of doubt in the minds of those at OSD/BOB level who control program

¹²United States, House, "Review of Army Tank Program," p. 35.

dollars," since it would make it appear that the Army lacked confidence in the program.¹³ The Armed Services Investigating Committee of the House of Representatives Armed Services Committee, from whose report the above quotation was taken, commented that the same attitude toward cover-up of technical difficulties because of funding implications was also seen in the MBT70 and Sheridan programs.

Engineering and service tests of 300 vehicles that were purchased in 1967 were suspended in 1969 until the system reliability problems could be overcome.¹⁴ In late 1971, the M60A1E2 was standardized as the M60A2. With the new turret, the weight of the M60A2 increased to almost 57 tons.

Since problems retarded the M60A2 and cancelled the MBT70 program (see below), the Army began a three-phase product-improvement program for the M60A1 in 1971. These improvements included main gun stabilization, a new long-life track, a solid-state ballistic computer, a laser rangefinder, an improved high-reliability engine, a modified torsion bar (tube-over-bar) suspension, and a more powerful electrical system. When these features are standardized, the tank will be redesignated as the M60A3. Component development is also underway in the engine, transmission, final drive, and night-vision systems for possible application at a later date. With these planned and potential improvements, the M60 tank will be serving in the U.S. Army well into the 1980s, 40 years after the line began with the T20 series in the early 1940s.

THE MBT70 PROGRAM

The MBT70 program has become synonymous with military mismanagement of technological development. The Army's troubles with this program were compounded by the fact that the Sheridan/Shillelagh and M60/Shillelagh systems were undergoing similar problems at the same time. The program was severely criticized in the Congress and press,

¹³ Ibid., p. 36.

¹⁴ In addition to the 300 vehicles, 243 Shillelagh-armed turrets had been purchased for retrofit on M60 chassis.

which exposed cost overruns, technical shortcomings, extended delays, and attempted Army cover-ups of the true situation. In the context of the total Army tank program over the years, the MBT70 must be seen as somewhat untypical; but as an illustration of a particular style of weapons acquisition, it is an all too common example.

The MBT70 grew out of a 1963 agreement between U.S. Secretary of Defense McNamara and West German Defense Minister von Hassel to jointly develop a new main battle tank for fielding in the early 1970s. Development began in early 1965. The intention from the start of the joint agreement was to build a revolutionary tank, new from the ground up. The tank was not defined, except that it would be the most advanced tank that the state of the art could provide in the 1970s.¹⁵ The U.S. project manager stated: "For the first time in the history of modern tank design, the designers of the MBT were given carte blanche to optimize basic design configurations into which they put an entirely new set of components developed by the best scientific know-how of the United States and Germany."¹⁶

The original MBT70 design included an automatic gun loader that reduced crew size to three; a variable height hydropneumatic suspension that enabled the tank to "squat" to reduce its silhouette and that permitted high-speed cross-country mobility; the 152-mm gun/missile launcher, combustible cartridge case ammunition, and guided missile; a variable compression ratio 1500-hp engine that could use a wide variety of fuels; a fully stabilized turret and a counterrotating turret capsule for the driver; a laser range finder and a new ballistic computer; a remotely controlled 20-mm cannon; an environmental control/life support system; and a quality assurance and reliability "never before realized in tank design...that should bring smiles to the face of battalion

¹⁵Ireland, p. 33. This approach, fostered by McNamara, went counter to the Army's development philosophy, which emphasized component development and an experimentally cautious treatment of wholly new designs. Prior to the formal agreement, the United States and Germany were jointly working on a component development program that they hoped to use when the components matured.

¹⁶DeAngelis, p. 7.

maintenance officers."¹⁷ The first prototype was operable by July 1967, but the joint, binational project management team quickly ran into technical difficulties, the resolution of which was hindered by the cumbersome management organization.

By 1969, development costs and project unit costs had skyrocketed, technical shortcomings were appearing on most subsystems, and the program was running behind schedule.¹⁸ Congressional disapproval of the program was growing. In 1969, the House Appropriations Committee recommended that the joint development program with Germany be terminated and that the Army "design a tank with far less sophistication, a tank that can be produced at about a third of the cost now estimated for the current design."¹⁹ An "austere" version of the MBT70, called the XM803, was designed in late 1969 and tested in 1970. The projected unit cost of the MBT70 was close to \$1 million in 1970, and the austere XM803 unit cost was said by the Army to be \$600,000, although independent estimates placed it closer to \$850,000. (For comparison figures, the unit cost of the M60A1 at that time was about \$220,000.)

In their FY1972 report, the House Appropriations Committee noted that the Army's cost estimates could not be supported, and that in all probability the unit cost could range from \$850,000 to over \$1 million. The report went on to state that "the Committee is firmly convinced that no tank is worth that much money."²⁰ The Committee continued to feel that the XM803 was still unnecessarily complex and sophisticated and that the Army had failed to satisfy the recommendations of the previous year. They recommended that all funds for the MBT70/XM803 be deleted from the budget and that the program be terminated. They then called for \$20 million to be added to the Army budget "for the purpose

¹⁷Ibid., p. 9.

¹⁸Information on the cancellation of the MBT70/XM803 program and events concerning the early history of the XM1 was obtained from Alexander (1975) and from unpublished interviews.

¹⁹United States, House, Report No. 91-698, p. 73.

²⁰United States, House, Report No. 92-666, p. 74.

of initiating a prototype program to build a limited number of tanks of two different designs for test and evaluation."²¹ They doubted the need for such extravagant features as a variable height suspension system, an automatic loader, and an antitank missile system, and specified that the designs "not be warmed over versions of the XM803."²² The Committee, with more general Congressional support, wanted a "relatively inexpensive" vehicle as quickly as possible. They looked upon the years and dollars spent since 1963 as largely having been wasted and were impatient with the Army over the conduct of its tank program.

THE XM1 PROGRAM

The Army's initial response to the Congressional mandate was to establish a Main Battle Tank Task Force in February 1972 with a charge to develop a requirement for a new tank within 6 months. The Task Force was the link between Congressional dictates and the development program that was to follow. In order to meet the strongly expressed demands for a relatively inexpensive tank, the Task Force compiled a catalogue of components that were available from United States or foreign sources. For a component to be placed in this catalogue, it had to have no greater than "moderate risk"--defined as having been built (i.e., available as actual hardware) and subjected to some testing with no known deficiencies. Tank designs were constrained to be assembled from the catalogued components. In addition to the cost and schedule constraints implicit in Congressional statements, the Army recognized that continuing support by Congress could not be taken for granted unless a convincing case for a new tank could be made. They believed that a substantial increase in performance was a necessary but not sufficient condition for further approval.

During the compilation of the components catalogue, it was seen that substantial increases in almost every dimension of tank performance would be possible, except in the area of armor protection. Task Force leaders thought that the lack of improved armor would significantly reduce the acceptability of a new tank. Colonel Charles Heiden,

²¹Ibid., p. 75.

²²Ibid., p. 105.

who was Deputy Director of the Task Force and responsible for its day-to-day operations, therefore began a search for new armor materials or concepts. As the search started, he heard rumors that a new material was in development. Prior to this time, Army laboratories had developed a new type of armor based on British armor research. This new armor would provide roughly twice the protection of currently available armor, but it was highly classified and only laboratory specimens had been tested. Through his wide circle of acquaintances and friends, Colonel Heiden heard of the existence of this potential solution to his problem, but it turned out that the new armor did not meet the moderate risk criterion demanded by the Task Force. Thus, the determination of fabrication costs and the protective capabilities of fabricated structures became a top priority.

Plans for the use of the new armor embroiled the Task Force in a debate as old as the concept of tanks--armor protection versus mobility. In the decades following World War II, increased penetrating power and the profusion of shaped-charge antitank weapons, together with the development of high-velocity kinetic energy rounds, had caused many analysts to question the need for heavily armored vehicles. It made sense, under these new conditions, to trade the increasingly useless mass of armor for lighter, more-agile, less-expensive tanks in larger numbers. The Task Force was attracted to a lighter tank at the lower end of the 40- to 50-ton range. However, the technological possibilities implicit in the new armor shifted the parameters in their calculations. A 58-ton design incorporating the new armor yielded 100 percent more protection than that provided in the current tanks. The increased weight, however, meant a less-agile, less-mobile vehicle unless a powerful engine and a good suspension system were available. They were--but at a cost.

The Task Force was overruled on their preferred choice of a light-weight tank by a Department of the Army review committee, whose decision was upheld by the Chief of Staff, General Creighton Abrams, himself a renowned World War II armor commander. It was the committee's belief that the Army could not recommend less protection for the American fighting man than was demonstrated to be available. The fact that

mobility could substitute for armor in providing protection was not an acceptable argument. Armor was something tangible, mobility was an analyst's concept. The importance of perceptions, especially when untested in an operational environment, is critical here. The experience and intuition of senior commanders to a large degree determined the tank's critical features.

The Task Force report included a draft Materiel Need document--the formal statement establishing the Army's requirement for a new weapon. It noted that in a confrontation with the Soviet Union, the United States would face large numbers of Soviet tanks and assumed that the numerical imbalance would continue in the future. The American tanks must therefore make use of major improvements in performance to compensate for an inferiority in numbers; they could also profitably take advantage of advances in infantry antitank weapons and attack helicopters. In particular, the tank would not be required to be the primary antitank system, especially at long range. This assumption allowed the Task Force to recommend a gun instead of a missile. It also meant that since the infantry could fill its own antitank needs, armor could be freed from a basically infantry-accompanying role. This would permit future tanks to concentrate on the classical armor tactic of mass movement, and enable them to exploit their mobility and capability to quickly close with enemy forces while simultaneously delivering accurate firepower.

The performance requirements were specified as bands: the lower level of the band would be attainable with available technology, but the upper level would push against the state of the art. The intention was to draw away from a growing tendency to overspecify performance and overconstrain designers. The new tank program, designated the XM1, was authorized for development by the Defense Systems Acquisition Review Committee in July 1971.

General Motors and Chrysler were selected to develop the competitive prototypes. Recognizing that program changes have been one of the principal sources of cost growth in the past, the project management office sought agreement throughout the Army to hold change requests to a minimum and to funnel them through a Tank Special Study Group for evaluation. The effect of a real cost constraint on changes in

requirements is illustrated by the following anecdote. An item the Study Group wanted to add to the XM1 was a telephone on the outside of the tank that could be used to speak to the crew on the inside. A representative from the project office to the Study Group told them that the cost would be \$300 and asked what they would remove from the tank that cost \$300. The Study Group "reacted as if a grenade had exploded on the table." They had not considered, nor were in the habit of considering, the relative value of performance characteristics.

One change in the program was imposed in 1974 by the Secretary of Defense, who was interested in promoting NATO standardization of weapons. He supported a German suggestion that the United States, United Kingdom, and Germany conduct a tripartite tank gun evaluation. The U.S. entry would be the 105-mm British-designed gun installed on the M60 and proposed for the XM1, firing improved ammunition. The British entry would be an upgraded version of the same gun in the form of a 110-mm rifled design. The Germans would enter a 120-mm smoothbore gun, firing fin-stabilized projectiles. Each country proposed a qualification test that would favor its own design: the Germans generally wanted to restrict the evaluation to consideration of armor penetration and accuracy; the British wanted the entire tank to be evaluated, including the number of rounds that could be carried and the rate of fire that could be sustained; the United States wanted the effect on the total tank force to be considered, including logistics requirements and the potential loss of commonality with tanks already in the field. The tests, completed in 1975, showed that each of the guns excelled in different dimensions of performance.²³ (Interestingly, a new round developed by the Picatinny Arsenal provided good competition for the German weapon, even on the Germans' own preferred tests.)

The Department of Defense later invited the Germans to participate in the XM1 prototype competition with their Leopard 2. Considerable redesign was necessary, however, to bring the German competitor up to the U.S. requirements established for the General Motors and Chrysler

²³"NATO Completes Tank Gun Trials," *International Defense Review*, October 1975, p. 635.

vehicles. The original XM1 prototypes were scheduled for delivery to the Army in February 1976, but the improved Leopard 2 could not match that schedule and was to be available for U.S. Army tests beginning in September 1976. Completion of testing and full-scale engineering development of the XM1 were to begin in June 1976, but a decision was announced in July to extend the validation phase by several months.

Results of XM1 testing indicate that armor, the riskiest element in the system, is proving to be less troublesome than expected. It has also been stated that the design-to-production cost goal of approximately \$580,000 per unit, at 1972 prices, is also being met. But only full-scale test and evaluation can substantiate the correctness of these claims.

The XM1 is a half-step away from the R&D strategy for tanks that the Army has used since about 1960 and that other Services have been involved with for a decade longer. The production-oriented, program-managed, high-technology, system-developed weapons have a history of high development costs, high procurement costs, late delivery, and unreliable performance. The XM1 avoids many of the potential pitfalls of these past programs. Costs are of primary importance for the first time in years. (Congress has mandated that.) Alternative prototypes are to be built and tested *before* production decisions are made. Performance specifications were not pushed to the utmost levels of technical feasibility. But despite the multiphased program schedule, the Army always expected the XM1 to be produced. The program was not intended, in its primary role, to be an experiment.

XII. THE DEVELOPMENT OF U.S. ARMOR: ARMOR PLATE OR GOLD PLATE--
THE PROBLEM OF COSTS

Since at least World War II, U.S. military planners have held the strong belief that high-quality weapons are necessary to meet the potential threat of large numbers of enemy weapons and troops. This belief is based, in part, on the demonstrated capability of U.S. science and industry in both wartime and peacetime. The huge number of tanks possessed by the Soviet Union, an outgrowth of their doctrine and capabilities, has helped to validate this belief.¹

Attempts to increase the quality of U.S. weapons through advanced technology, however, have not been uniformly successful. The costs of successive generations of many weapons systems have been increasing by factors of 5 to 10 per decade since World War II. The MBT70/XM803 program was terminated by Congress because of excessive costs. The Sheridan/Shillelagh and M60A2 programs were plagued by high costs, unreliable equipment, and delayed delivery. The projected costs and proposed technology of the Army's new XM1 tank has received close scrutiny by Congress. And Congress is not the only source of complaints. Defense officials have joined the widening group of critics concerned about growing weapons costs.² This criticism, and an apparent growing reluctance on the part of Congress to finance expensive systems generated by the doctrine of quality, has created a serious dilemma for the military and for the country. Is it possible to achieve desired levels of performance at a price that the country is willing to pay?

¹Since the end of the Korean War, the disparity between the number of tanks possessed by the United States and the Soviet Union, and between NATO and the Warsaw Pact countries, has been growing. The Soviet Union's present inventory of some 40,000 tanks is almost five times as great as that of the United States. Tanks available to NATO within 30 days after the beginning of a major European land war are estimated to be only half the number available to the Warsaw Pact countries.

²See, for example, the article by Norman R. Augustine, Assistant Secretary of the Army for Research and Development.

FACTORS AFFECTING COST ANALYSIS

Several earlier studies have suggested that the cost explosion observed in other weapons has also been true of tanks, but to a lesser extent. One analysis extending back to World War I shows a doubling of tank costs in each decade.³ Another indicates the same rate of cost growth since World War II.⁴ However, these two studies, and most others examining the problem, suffer from several faults. For example, the first study does not account for inflation, whereas the second one does. Curiously, both studies arrive at the same conclusion: that costs double every 10 years, despite their different treatment of inflationary price changes.

Sample selection can also affect results. The post-World War II cost analysis was based on observations of only 8 tanks.⁵ These included three models of one tank (M48), three of another (M60), and two tanks (MBT70, XM1) that were never produced, but whose costs were only planning estimates. The present analysis attempted to meet several objectives in compiling cost data: (a) The set of observations should be as inclusive as possible to avoid biases (in unknown directions) introduced by selective sampling. (b) Inflation must be taken into account. (c) Adjustments should be made for cost variations due to widely different production quantities. (d) Costs should be defined in a consistent manner. Since the cost data were collected from a number of sources published over a 50-year period, these objectives were met with varying degrees of success.⁶ Nevertheless, the major points that emerge from the analysis do not seem to be sensitive to the residual problems with the data.

COST TRENDS

Since World War I, tank production costs (adjusted for inflation) have crept upward quite slowly--at a rate of approximately 1.5 percent

³Ibid., p. 36.

⁴Sullivan.

⁵Ibid.

⁶For greater detail on the data and analysis, see the appendix to this section (p. 123).

per year--if the recent experience coming out of the project-managed, high-technology programs is ignored (see Fig. 1). This broad view, however, masks several interesting short-term movements. For example, from 1945 to 1964, the cost of those medium tanks that evolved from the M26 fell by about 2.5 percent per year. But over the next decade, from 1965 to 1975, the cost of the M60A1 increased at an annual rate of approximately 3 percent despite the absence of major design changes to that model.⁷

The most important trend in Fig. 1, however, is the sharply increased costs of developments associated with the change in R&D strategy beginning in the late 1950s.⁸ Since this cost explosion overshadows past experience in the minds of most observers, the continuous and cumulative technological progress, accompanied by only minor increases in costs over 50 years of U.S. tank development, is easily ignored.

This point is made even more strongly when the cost is calculated on a weight basis. Since the observations included vehicles whose weights ranged from 3 to 58 tons, differences in tank size can obscure underlying trends. The cost per ton (in 1972 dollars) is plotted in Fig. 2. Except for the World War I models, cost per ton fell slowly until the late 1960s, with most of the observations occurring within

⁷There are several alternative hypotheses to explain this change in the direction of costs of medium tanks. Production rates fell sharply in the mid-1960s from approximately 1000 per year to 360, whereas numerous minor production changes continued to be made. With the lower production rates, these changes may have precluded cost reductions from the learning effects one usually observes over the length of a production run. Also, learning-curve effects may have been largely exhausted by the mid-1960s, since similar vehicles had been produced for more than a decade. A simpler explanation is that productivity in the tank plants rose at a slower rate (for whatever reason) than in the sector "Machinery and Motive Products," whose experience is used to deflate tank costs. Alternatively, large numbers of minor product improvements may have increased the quality and value of the tank without concurrent changes in model numbers or designations.

⁸The two points for the MBT70 (from bottom to top) represent the final Army estimate and an independent Government Accounting Office estimate. The M60A2 cost for 1967 includes only initial production costs. These vehicles were stored for several years until many changes could be made to them to bring them up to usable standards.

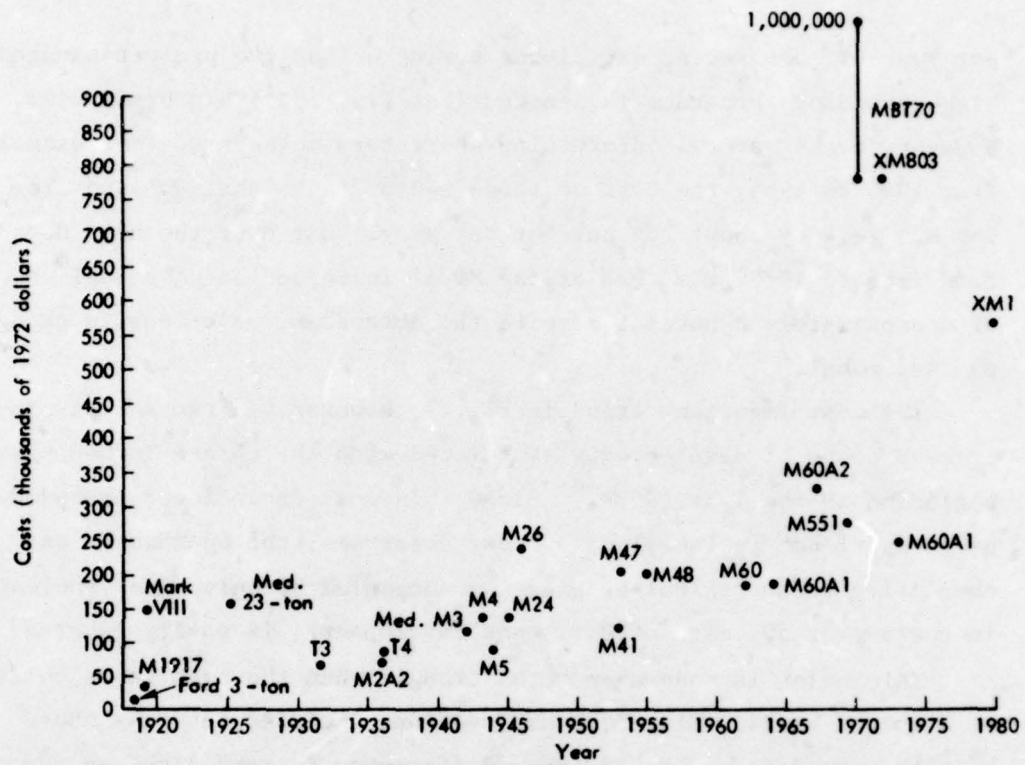


Fig. 1—Tank costs, 1918-1980: 1972 dollars

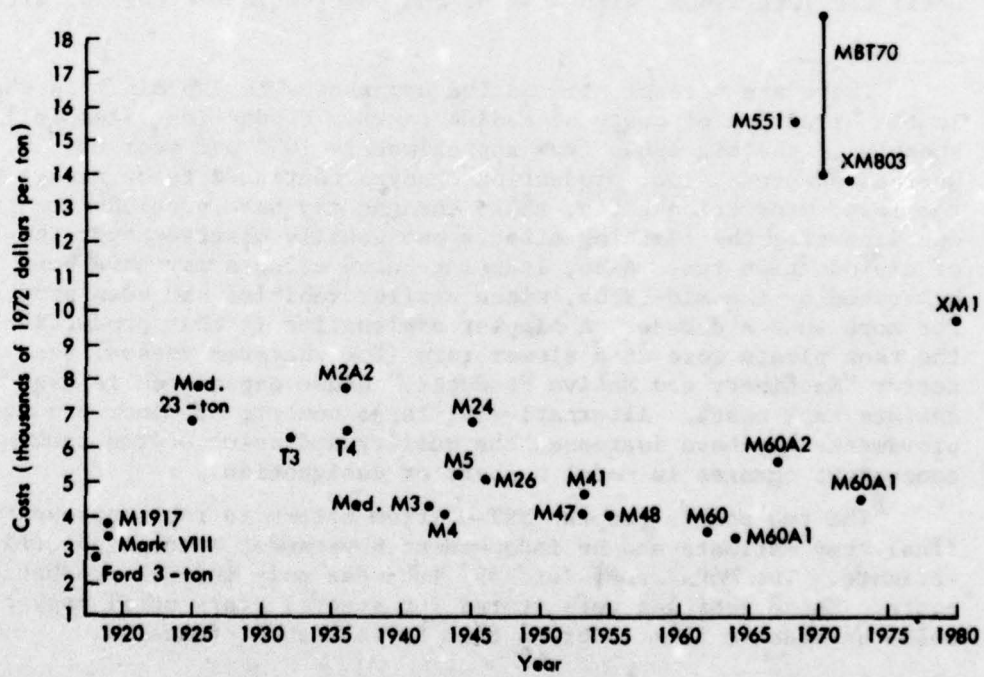


Fig. 2—Tank costs, 1918-1980: 1972 dollars per ton

the relatively narrow range of \$3500 to \$7000.⁹ Costs then jumped sharply to over \$15,000 per ton for the M551 Sheridan and to \$19,000 for the MBT70. The XM1, at just under \$10,000 per ton, is still considerably higher than the range of past experience.

SOURCES OF HIGHER COSTS

Some of the sources of these higher costs can be uncovered by comparing the M60A1 with the M60A2, which had the same hull but a different turret and armament. Much of the cost difference between these models is attributable to the gun/missile launcher, fire control, and turret stabilization of the M60A2. (Production contract costs of the M60A2 and M60A1 for FY1967 and FY1968 are shown in Table 3.) The remaining cost differential between the two models resulted from integration of the new turret with the hull.

One of the reasons for the high cost and unreliability of the M60A2's gun/missile system was the attempt to rush the system into production prior to its full development and testing.¹⁰ Curtailing the time for testing, evaluation, and design revision has been a well-demonstrated cause of technical difficulties and cost growth in weapons systems. These effects are particularly serious when the performance sought in the new system is a major advance over that of previous systems.¹¹ Another increasingly important source of potential problems is the growing use of electronics in tanks. If aircraft are a valid analogy, electronic devices are likely to result in increased testing

⁹ Extending the observations back to 1918 increases the possibility of measurement error. Prices during World War I were highly volatile, with price indices varying by as much as 75 percent over a period of a few years. Also, as described in the appendix to this section, a different price index was used for the years prior to 1939; this index may have behaved differently from the index used for later years.

¹⁰ In 1964, the Department of Defense approved a plan to apply the gun/missile system to the M60 on a "crash basis" until the new MBT70 became available. The rationale for doing this was an alleged "quantitative and possible qualitative superiority" of Communist Bloc armored units. See United States, House, *Review of the Army Tank Program*, pp. 2, 5.

¹¹ For evidence on these points, see Perry et al.; Nelson and Timson; Nelson et al.; and Harman.

Table 3

COMPARISON OF THE PRODUCTION CONTRACT COSTS OF
THE M60A1 TANK^a AND THE M60A2 TANK^b

Component	M60A2 (FY1967)	M60A1 (FY1968)
Engine	17,600	18,468
Transmission	11,095	11,400
Track	4,400	4,400
Hull	18,400	19,444
Turret	9,800	9,111
Ballistic computer	--	1,910
Rangefinder	--	3,500
Gun and mount	--	13,098
Gun/launcher	15,376	--
Stabilization system	23,895	3,417
Missile and guidance control	40,297	--
Total cost	278,043 ^c	182,386

SOURCE: United States Army Weapons Command,
*Procurement History and Analysis of M60 Tank
Family*, AMSWE-PPR-69-02, January 1969.

^aEquipped with a 105-mm gun.

^bEquipped with a Shillelagh missile and a
152-mm gun/launcher.

^cMany other changes, at additional cost, were
required to bring the M60A2 to usable levels of
performance.

requirements, decreased reliability, and difficult maintenance prob-
lems.¹² Applying the lessons of history to the XM1, with its laser
rangefinder, sensors, gyros, computer, and stabilization system, cost
projections may well be optimistic.

COST COMPARISON OF U.S. AND SOVIET TANKS

U.S. tanks, with the exceptions noted above, have exhibited
reasonable price behavior over the years, but how would the cost of
the M60A1 compare with that of the Soviet T-62? Simple calculations

¹²These points are treated in Nelson et al.

will suffice to demonstrate the major differences in costs between these two tanks.

Even though they were introduced at just about the same time, the T-62 is less complex in almost every subsystem than its American counterpart. It has a manual transmission, a manual, lateral, lever-type steering mechanism that is only a step more complex than primitive clutch and brake mechanisms, a 40-year-old engine, and little attention paid to crew comfort. It lacks a rangefinder and has only a fraction of the vision devices found in the American tank. The Soviet tank is also approximately 20 percent lighter than the M60A1, which has automatic transmission, infinitely variable power steering, a rangefinder, greater interior room for crew comfort and ammunition storage, and is generally more complex.

If it is assumed that the T-62 costs perhaps 20 percent less per ton than the M60A1, its total cost should be approximately two-thirds as much.¹³ Applying this figure to the M60A1 cost of \$146,005 in 1964 (by which time production of both tanks had stabilized) yields a T-62 cost of \$93,440--or in rough terms, under \$100,000. When converted to 1972 U.S. dollars, this would be around \$125,000. In the meantime, the cost of the M60A1 has crept up by about 3 percent per year. The T-62 would most likely have held steady, or even decreased because of the apparent stability of its design and a production rate 10 times that of the M60A1. Taking these factors into account, today's U.S. tank is about twice as expensive as its Soviet counterpart. The projected cost of the XM1 would be approximately five times greater.¹⁴

An important question is whether the higher level of performance in the American equipment is worth the extra price; or alternatively, whether the lower capability of the Soviet T-62 is offset by its lower price. Determining the relative efficiency of weapon systems developed in two very different countries is a task fraught with ambiguity.

¹³This estimate (and method of arriving at it) is very similar to one made by a U.S. tank manufacturer who physically examined a T-62.

¹⁴This cost comparison is sensitive to the year in which the comparison is made. In any comparison, however, the relative trends noted above should not be ignored.

However, there is evidence to point toward a credible answer. During the Arab-Israeli War of October 1973, Israeli units fought with and against M60s and T-62s. Analysis of that combat, and interviews with Israeli commanders and participants in armored combat, suggests that the M60A1 was marginally superior to its Soviet counterpart, especially at long range where the rangefinder, computer, and ballistic characteristics of the U.S. tank gun paid off. Also, crews appeared to be more efficient after long hours of duty in the tank. The T-62, however, was smaller, harder to see, and harder to hit. It possessed good mobility, and its high-velocity smoothbore gun was highly effective at ranges up to 1500 m, although the smaller number of rounds that it carried was a negative feature.¹⁵ But the overall assessment was that differences in command skills, crew training and capability, and local terrain conditions often dominated the technical differences in the tanks themselves.

¹⁵ The Israelis reported that large numbers of Arab tanks were abandoned after the basic ammunition load was expended. This may have been caused by poor firing discipline or simply by crew panic. Nevertheless, both their own and their enemies' experience have caused the Israelis to place great emphasis on increasing the number of main gun rounds that the vehicle can carry.

Appendix to Section XII
U.S. COST DATA ANALYSIS AND SOURCES

PRICE INDEX

When comparing the prices of particular products over periods of time in which prices of all goods and services have been changing, it is necessary to adjust for economywide inflation in order to isolate the real shifts in relative prices of the compared products. Adjustment for inflation is made in this report because interest does not center around purely monetary price changes, but around differences in *real resources* required to produce the product. A price index was desired that would capture the real cost and productivity experience of the tank-producing sector. A price index for the "Machinery and Motive" sector (more recently, "Machinery and Equipment") was chosen for its historical and industrial coverage.¹ Unfortunately, this index is only available historically after 1939. A broader index covering the "Metals and Metal Products" sector was therefore used for the earlier years. The latter index is somewhat more volatile than the "Machinery and Motive" index, having increased 13 percent more over the 35 years common to both indices.

PRODUCTION QUANTITY

Quantity affects production costs in two ways. High-volume production justifies an investment in high-quality tooling, which reduces unit costs. But, independently of the quality of the tools, as production progresses, costs typically fall through a learning effect as accumulated experience reveals ways of doing the job more efficiently. Both of these effects are illustrated by the cost of the M4 Sherman in plants that produced large and small numbers of the tank. At the high-volume Chrysler-operated Detroit Tank Arsenal, production costs were \$42,400, whereas at the Federal Machine and Welder Company, the

¹These data were taken from the *Economic Report of the President* and from *Historical Statistics of the United States*, p. 117.

cost was \$70,000.² Similarly, for the first contract of 180 M60 tanks, the average cost was \$274,000. Four years and 2200 M60s later, costs fell to \$145,000.

In this report, costs arising from very small production quantities were adjusted by assuming a production run of 1000 units and a 90 percent learning curve.³ This adjustment principally affected tank models of the 1920s and 1930s. In other cases, the last or lowest available cost figure was used.

PRODUCTION COSTS

Where possible, production costs (including government-furnished equipment) were chosen. Production costs do not include research and development expenditures, spares, transportation, fuel and ordnance, or other ownership and user costs. Also excluded in some instances is the cost of changes required to correct faulty equipment. This is especially true of the M60A2 in 1967. Production costs can differ from other cost figures that are commonly reported. For example, the Congressional appropriation for tanks for a given year is often divided by the number procured to derive a "unit cost." This calculation can hide transfers between programs, transfers between years, and the purchase of additional equipment under the appropriation. Such figures can often deviate substantially from actual production costs.

DATA SAMPLE

Table 4 shows the cost data and sources used in Section XII. Where several cost figures were published, the one that was chosen corresponded best to the goals set out above. However, at times it was necessary to choose on the basis of consistency among estimates or on the basis of reasonableness. For example, six cost figures from different sources were found for the M48. These varied from \$93,000 to \$271,000. However,

² Thomson and Mayo, p. 256.

³ A 90 percent learning curve implies that a doubling of the number of units produced will reduce the cost of the last (marginal) unit to 90 percent of the marginal cost prior to the doubling.

three of these six estimates were within 1 percent of \$132,000. In addition, the cost of the M60, which was quite similar to the M48, was known with good reliability to be close to \$145,000.⁴ Therefore, the \$132,000 figure for the M48 was chosen to be included in the data sample.

When more than one source published the same cost information, Table 4 gives the more readily available source.

Most of the figures given in Table 4 can be considered as point estimates from a distribution of possible alternative costs. Variability in the raw figures indicates that the "true" value could be 25 percent smaller or larger than the figure shown. This uncertainty narrows for recent years and widens for earlier years.

⁴This figure refers to costs in the fourth year of production when learning-curve effects had stabilized.

Table 4
COST OF U.S. TANKS

Model	Year	Actual Cost (current \$)	Quantity Adjusted Cost (current \$)	Price Index (1972=100)	Actual or Quantity Adjusted Cost (1972 \$)	Weight (tons)	Cost/Ton (1972 \$)	Source and Comments
Ford 3 ton	1918	4,000	--	48.0	8,330	3.1	2,690	Crowell, p. 156. Cost estimated on order of 500; 15 actually delivered.
Mark VIII	1919	85,000	59,900	41.6	144,000	43.5	3,310	Ogorkiewicz (1960), p. 297. 100 produced; \$35,000 estimate for 1500.
M1917	1919	11,500	--	41.6	27,600	7.5	3,690	Schreier, p. 47.
Medium 23 ton	1925	81,250	53,500	34.5	155,000	23	6,740	Green et al., p. 45. Estimate made for 64 tanks; none actually produced.
T3 and combat car T1	1932	34,500	162,000	24.4	66,400	10.5	6,320	Hofmann (1975), p. 15. 7 produced.
T4	1936	46,000	24,500	28.0	87,500	13.5	6,480	Augustine, p. 36. 16 produced.
Light M2A2 and M1A2	1936	27,500	21,000	28.0	75,000	9.6	7,810	Miller, p. 207. 170 produced.
Medium M3	1942	43,000	--	36.3	118,500	27	4,390	Augustine, p. 36.
M4	1943	50,000	--	36.2	138,100	34	4,060	Standard Nomenclature List G1, April 26, 1944. (See note at end of table.)
M5	1944	32,500	--	36.2	89,800	17	5,280	Standard Nomenclature List G1, April 26, 1944. (See note at end of table.)
M24	1945	50,000	--	36.5	137,000	20	6,850	Icks, <i>Light Tanks M22 Locust and M24 Chaffee, AFV/Weapons Profile</i> (Number 46), p. 110. Published cost excluded government-furnished equipment; \$10,000 added as estimate of GFE.

M26	1946	109,000	--	40.9	237,000	46	5,151	See note at end of table.
M47	1953	130,000	--	62.7	207,300	50	4,150	See note at end of table.
M41	1953	77,000	--	62.7	122,800	26	4,720	Ogorkiewicz (1960), p. 297. Augustine, p. 36.
M48	1955	133,000	--	65.4	203,400	49.5	4,110	Ogorkiewicz (1960), p. 296. (See note at end of table.)
M60	1962	145,000	--	78.3	185,200	51	3,630	U.S. Army, Materiel Command, "Cost Analysis Technical Report, M60 Series Tank," December 1968. (See note at end of table.)
M60A1	1964	146,000	--	78.9	185,000	53	3,490	U.S. Army Weapons Command (1969).
M60A1	1973	256,000	--	103.2	248,000	53	4,680	U.S. Army, Army Materiel Command, M60 Project Office. (See note at end of table.)
M60A2	1967	278,000	--	85.0	327,000	57	5,740	U.S. Army Weapons Command, <i>Procurement History and Analysis of M60 Tank Family</i> , AMSWE-PPR-69-02, January 1969.
M551	1968	240,000	--	87.5	274,300	17.5	15,670	U.S. Army, "Selected Acquisition Report--M551," July 15, 1970, p. 8. Average cost for 1965-1970.
MBT70	1967	520,000	--	85.0	611,800	50	12,240	U.S. Army, "Selected Acquisition Report--Program Main Battle Tank," October 14, 1969, pp. 6, 8n. Earliest estimate based on firm configuration.
MBT70	1970	743,000	--	94.5	786,200	55.5	14,170	U.S. Army, "Selected Acquisition Report--Program Main Battle Tank," October 14, 1969, p. 8n. Estimate assumes 2000 at 30 per month.
MBT70	1970	1,000,000	--	94.5	1,058,200	56	18,900	Government Accounting Office and other estimates.
XM803	1972	781,000	--	100.0	781,000	56	13,950	Government Accounting Office. Army Estimate \$700,000 with GFE.
XM1	1980	--	--	--	570,000	58	9,830	Design-to-cost goal in 1972 prices.

NOTE: Information supplied by U.S. Army, Tank Automotive Command, Historical Office.

XIII. CONCLUSIONS: A LONG-RUN STRATEGY FOR R&D

A long-run research and development strategy for systems that exhibit historical continuity can be abstracted from the development of tanks in the United States and the Soviet Union.¹ This strategy consists of three main elements: (1) product improvement of existing designs; (2) independent development of components and technology; and (3) construction and testing of experimental prototypes. Over the years, this strategy was the explicit policy of the U.S. Army and, by inference from behavior, was the dominant mode of Soviet tank development. All three elements appear to be necessary for the efficient advancement of both technology and performance.

PRODUCT IMPROVEMENT

Product improvement of existing designs is well illustrated by the stream of developments that converted the World War II medium-tank designs in both countries into today's main battle tanks. This process is illustrated for the M60 in Fig. 3a. The turret from the T42 went into the M47. A new engine and transmission went into the M46, and a dieselized conversion of this engine was installed in the M60. The M48 received a new hull, turret, and improved 90-mm gun. A new British 105-mm gun was used in the M60, and a more reliable engine, greatly improved ammunition, gun stabilization, and a series of other improvements are being added to the M60A3.

Soviet improvement of the World War II T-34/85 proceeded in similar manner, as shown in Fig. 3b. A torsion bar suspension, new transmission, and new hull appeared on the T-44 at the close of the war. Later versions of this tank carried a 100-mm gun that had been installed in an earlier self-propelled mount. The T-44 seemed to be an unreliable

¹Historical continuity implies that systems of a similar type have existed in the past and that information embodied in the previous experience has not been lost. The long-run policies described here are consistent with--and indeed are an extension of--project strategies outlined in earlier research. (See, for example, Klein et al. and Perry et al.)

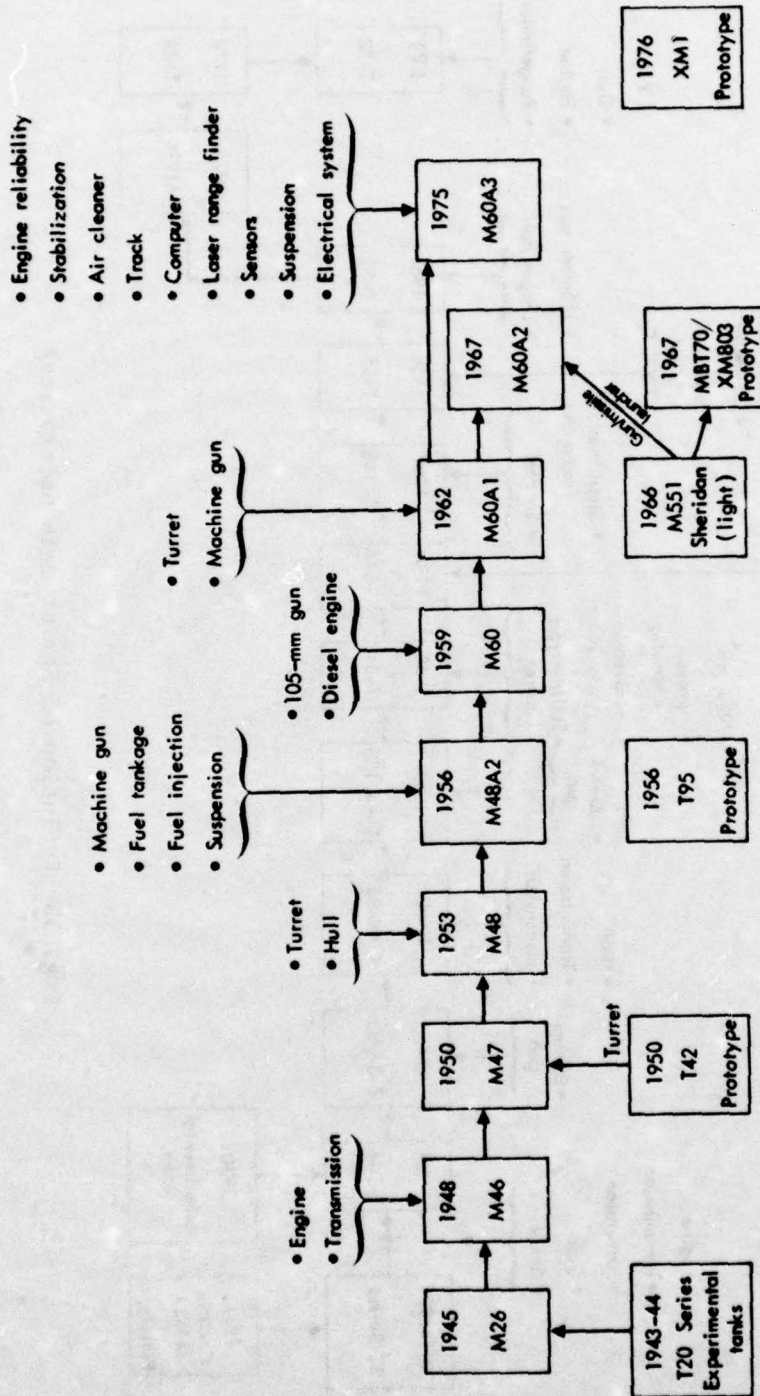


Fig. 3a—Evolution of U.S. main battle tank

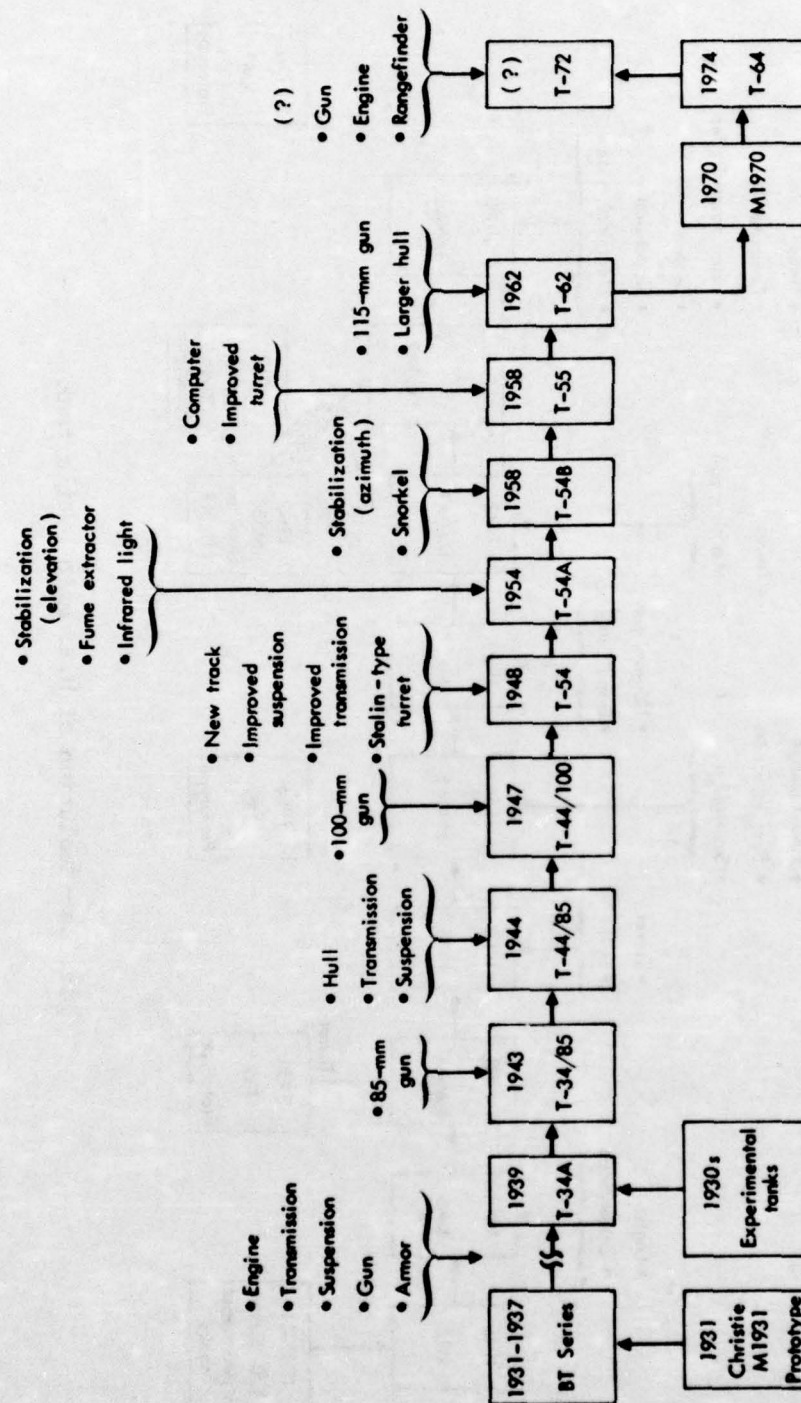


Fig. 3b—Evolution of Soviet main battle tank

and immature design, especially with respect to the new automotive components. These problems were solved in the T-54 by improving the suspension and transmission systems. A stabilized system made its first appearance on the T-54A, but only the vertical movement was controlled. Two-dimensional stabilization was added to the T-54B. The T-62 incorporated a new smoothbore, high-velocity, 115-mm gun in a slightly larger hull.

Technological advance through product improvement and evolutionary change acts to control the uncertainty of any R&D program largely by placing constraints on the size of the problem. Technical uncertainties are limited because much of the equipment remains unchanged. Developmental resources can then be concentrated on the new features.² Test results are therefore more easily analyzed than when many things change at the same time. Operational uncertainties are constrained for the same reasons. Since new developments are often undertaken to correct known deficiencies, or to make specific improvements suggested by previous operations, the conduct of operational testing and evaluation is simpler than for a wholly new system.

An additional example of effective product improvement is the Israeli experience with the World War II M4 Sherman. In 1943, the M4 suffered from relatively thin armor, high silhouette, high ground pressure on narrow tracks, and lack of firepower. The Israelis, who had acquired this tank in the early years of their independence, began their modification by replacing the gun, first with the 76.2-mm rifle of the U.S. M10 tank destroyer and then with the high-velocity 75-mm gun of the French AMX13 (and with other gun/turret combinations). A new turret, wider tracks, new suspension, and a diesel engine completed the renovation. Israeli tank commanders claim that the improved Sherman is superior in many ways to their Pattons or British Centurions.³ In the 1967

²R&D costs to convert the M48 to the M60A1 were less than \$10 million when all other applicable R&D programs, such as ammunition and gun developments, are included. The MBT70, on the other hand, cost the United States \$305 million, Germany \$100 million, and an estimated \$180 million more to complete development. (See United States, Senate, *Fiscal Year 1974 Authorization...*, April 1973, pp. 1988, 2008.)

³Marshall, p. 20.

Arab-Israeli War, the improved Sherman demonstrated its capability against the Soviet T-54 and T-55 in tank-to-tank combat "largely because its high-performance gun obviates the need to get as close as the undergunned World War II Shermans had to get."⁴ Israeli use of the improved Sherman in the October 1973 War gives this tank an active life of more than 30 years. The point of this discussion, however, is not to argue that a product-improved Sherman is equivalent to a modern battle tank, or that evolutionary improvement is the answer to every demand for increased performance, but rather to demonstrate the potential for large improvements through a series of incremental changes.

COMPONENT AND TECHNOLOGY DEVELOPMENT

In order to provide the improved elements for an evolutionary development strategy, separate, continuing development of components and technology is necessary. This was the stated policy of the U.S. Army in the 1920s and again in the post-World War II period. The diesel engine used in Soviet tanks since 1939 is an example of a component development that took place in parallel with ongoing system developments.

Post-World War II U.S. development of tank engines, transmissions, suspension systems, armor, armament, and ammunition also demonstrates the advantages of the approach. The engine used on the M60, for example, was the result of a 1947 plan to develop a series of air-cooled engines, utilizing the technological advances achieved in the recent war experience. The unit parts could be used on engines of 1 to 16 cylinders. This air-cooled engine has subsequently been used in a large number of Army vehicles. Improved ammunition for the 15-year-old gun on the M60 is a more recent example of an ongoing component development policy. The new ammunition provides the equivalent performance of a larger gun without the penalties inherent in a larger caliber. Also, since the gun itself remains unchanged, logistics and standardization are not affected.

A component development policy is a natural complement to a product-improvement strategy. A major criticism of the component-development

⁴"Durable Sherman East of Suez," *Army*, December 1973, p. 8.

approach has been that when the components are directed at a specific system at a specified date, either the component or the system may not be successful and the efforts devoted to both will have been wasted. With parallel ongoing development, however, this is much less likely to happen. Improvements can be added when the components reach a certain point of readiness, and there is usually a system awaiting improvement. Occasionally, however, some components may never reach such a point. This may occur for a variety of reasons--technical problems, costs, shift of requirements, etc. But, it is far better for a component to be found wanting at the development stage than at the time of final system integration.

EXPERIMENTAL PROTOTYPES

Product improvement, even when nourished by a stream of new components and technology, may eventually arrive at a point of diminishing returns. At times, it becomes desirable to try a wholly new approach. This is where the third element of the development strategy makes its contribution. Austere, experimental prototype construction should be a regular means of assessing new configurations, novel combinations, and especially wholly new concepts. The Christie tanks of the 1920s and 1930s were examples of experimental concepts. They were appreciated as such by the Russians, but U.S. Army Ordnance was seeking a finished product. The T20 series leading to the M26, the T42 and T95 medium tanks, the T43 heavy tank, and the T92 light tanks were postwar experimental prototypes that efficiently tested out new concepts and components, some of which eventually appeared on production vehicles, whereas others were demonstrated to be less useful or infeasible.

The experimental prototype is the appropriate technique for determining whether an older product is no longer worth improving and whether a new development ought to be undertaken. But, it is important that such programs be planned in a "question mark" mode rather than in an "exclamation point" style: They should be explicitly and consciously used to ask questions, not to make assertions. That was the difference between, for example, the T95 and the MBT70. A development program of a technologically advanced system that does not recognize the inherent

uncertainty of technological change and that does not structure the process in a sequential, flexible way designed to resolve the technological uncertainties will inevitably face serious difficulties of cost, schedule, and performance when unexpected problems arise.

AN ALTERNATIVE STYLE OF DEVELOPMENT

For many American weapon systems of the post-World War II period, an alternative development strategy was adopted. It was believed that uncertainties could be adequately managed through analytical studies and thorough engineering. In general, this belief turned out to be unfounded. Systems were too complex, and desired technological advance was too great to be treated by the scientific and engineering knowledge and techniques that were available.

The "weapons system concept"--by which I mean the attempted optimization of high performance equipment through simultaneous development of equally high-performing subsystems, together with voluminous analysis--became the standard approach to weapons development. Some of the most successful programs of the past quarter century were outstanding examples of the efficacy of the weapons system concept. The Manhattan Project and B-29 development of World War II, the Atlas and Minuteman I ballistic missile program,⁵ and the Polaris submarine and missile developments were exceptional programs that transformed the services--their budgets, roles, and missions. The success of these programs brought forth a succession of imitative efforts whose unsuccessful outcomes suggest that it is not possible to standardize the exceptional. Mimicry of misperceived experience has generally resulted in crucial omissions. The outstandingly successful programs were characterized by high-level political commitment, autonomy of internal management, strong and highly competent program leadership, and a public (or Congressional) willingness to place a high priority on an agreed-upon national goal. Smaller "skunk-works" programs that have also been unusually effective share many of

⁵ Minuteman II and III are outstanding instances of sequential product improvements. The early stages of the Atlas development paid careful and explicit attention to sequential decisions and experimental, parallel alternatives.

these same attributes.⁶ That these conditions are rarely attainable, though, has not lessened the attraction of that style of system development, either in the military or in nonmilitary government-financed programs. Moreover, such programs are usually quite large, requiring a mobilization of political and organizational participants and supporters. This support, however, can generally be obtained only through a loss of project autonomy when those who have committed themselves to the program have also assumed an implied right to participation in the detailed management.

A tendency toward diffuse decisionmaking authority in public affairs is an abiding feature of American culture that generates a complex array of procedures and regulations to provide the required coordination of the widespread decision authority. Out of this necessity for coordination come procedural complications and rigidity.⁷ When the weapons system style of development was linked to the historical American predisposition to diffuse decisionmaking, the number of regulations, regulators, and the regulated became unmanageable and overconstraining. The efficiency of the R&D process necessarily declined. Because of the pervasiveness of these organizational and cultural forces, efficiency in R&D would seem to require keeping programs as small as possible for as long as possible.

IN SUMMARY

Product improvement has been the primary mode of increasing the value of tanks. It is relatively cheap and certain. The results are easily tested and can be evaluated against a base case of earlier models. However, continuous product improvement can lead to diminishing returns. But how can one tell when to end a particular line of development and what the new configuration should look like and include? The answer has been found in the construction of experimental prototypes. Prototypes provide a better way to test hardware than any paper analysis, computer simulation, or intuitive judgment. But without an improving

⁶ See Perry et al. for examples of such programs.

⁷ See Crozier, pp. 231-236.

technological base and an independent component development program, there would be nothing to feed into either the product-improvement stream or on which to base experimental prototypes. All three elements of the R&D strategy have been required for efficient development over time.

Because tanks are examples of relatively slow-moving technology, the application of this R&D strategy to products in rapidly changing fields may be questioned. However, for products as diverse as aircraft and missiles, computers and integrated circuits, a similar strategy has been employed with success. The chief difference between these items and tanks is the shift in emphasis from product improvement to new technology and the construction of experimental prototypes. However, general applicability of the R&D strategy can only be determined by further research.

The present state of armor development is fluid and open. Not only is technology changing, but potential threats are also changing--both in terms of where and with whom U.S. forces may be engaged, as well as the weapons that may be employed. Soldiers are fond of speaking of the fog of battle, but the fog of peace is even more impenetrable. Potential enemies, weapons, and geographical conditions can be observed only hazily and are continually shifting. An appropriate R&D policy is one that recognizes the uncertainty and fluidity of the situation. However, it is not always possible to achieve this ideal, even when it is the expressed goal of an organization. We must therefore better understand the reasons for past behavior and the barriers to implementation of new policy. The lack of such an understanding remains the main practical obstacle to improving the way we develop technologically advanced systems.

BIBLIOGRAPHY

- Alexander, Arthur J., *R&D in Soviet Aviation*, The Rand Corporation, R-589-PR, November 1970.
- Alexander, Arthur J., *Weapons Acquisition in the Soviet Union, United States, and France*, The Rand Corporation, P-4989, March 1973.
- Alexander, Arthur J., "XMI," in Commission on the Organization of the Government for the Conduct of Foreign Policy, Appendices, Volume IV, *Adequacy of Current Organization: Defense and Arms Control*, U.S. Government Printing Office, Washington, D.C., June 1975.
- Alexander, Arthur J., and J. R. Nelson, *Measuring Technological Change: Aircraft Turbine Engines*, The Rand Corporation, R-1017-ARPA/PR, May 1972.
- "An Unsatisfied Customer," *Aviation Week & Space Technology*, July 7, 1975, p. 7.
- Augustine, Norman R., "One Plane, One Tank, One Ship: Trend for the Future?" *Defense Management Journal*, April 1975, pp. 34-40.
- Bailey, Charles H., "Pershings for Normandy: An Ordnance Myth," *Armor*, September-October 1975, pp. 26-29.
- Blumenson, Martin, *The Patton Papers: 1885-1940*, Houghton Mifflin Company, Boston, Mass., 1972.
- Brown, James D., "Medium Tank Doctrine--The Sherman Era," *Armor*, November-December 1973, pp. 22-26.
- Chamberlain, Peter, and Chris Ellis, *British and American Tanks of World War II*, Arco Publishing, New York, 1969.
- Chamberlain, Peter, and Chris Ellis, *M3 Medium (Lee/Grant)*, *AFV/Weapons Profiles*, Number 11, Profile Publications, Windsor, Berkshire, England.
- Chamberlain, Peter, and Chris Ellis, *M4 Medium (Sherman)*, *AFV/Weapons Profile*, Number 29, Profile Publications, Windsor, Berkshire, England.
- Clark, Alan, *Barbarossa*, William Morrow & Company, New York, 1965.
- Crow, Duncan (ed.), *British AFVs 1919-40*, Profile Publications Limited, Windsor, Berkshire, England, 1970.
- Crow, Duncan, and Robert J. Icks, *Encyclopedia of Tanks*, Barrie & Jenkins, London, 1975.
- Crowell, Benedict, *America's Munitions: 1917-1918*, Report of the Assistant Secretary of War, Director of Munitions, U.S. Government Printing Office, Washington, D.C., 1919.

Crozier, Michel, *The Bureaucratic Phenomenon*, The University of Chicago Press, Chicago, Ill., 1964.

"Czechs View Soviet vs. Western Transport," *Aviation Week & Space Technology*, January 13, 1969, pp. 67-79.

DeAngelis, Joseph A., "MBT70: Armor's Equalizer for Future Tank Warfare," *Armor*, November-December 1967, pp. 4-10.

"Development of 105-mm Gun Main Battle Tank, M60 Series," Technical Information Report 3-1-2J2(1), Office, Chief of Ordnance, September 1961.

"Durable Sherman East of Suez," *Army*, December 1973, p. 8.

Economic Report of the President (Transmitted to the Congress January 1976), U.S. Government Printing Office, Washington, D.C., 1976.

Eisenhower, Dwight D., *At Ease*, Doubleday & Co., New York, 1967.

Ellis, Chris, and Peter Chamberlain, "American Tanks," in Duncan Crow (ed.), *AFVs of World War One*, Profile Publications, Windsor, Berkshire, England, 1970.

Ellis, Chris, and Peter Chamberlain, *Light Tanks M1-M5, AFV/Weapons Profiles*, Number 4, Profile Publications, Windsor, Berkshire, England.

Erickson, J., *The Soviet High Command*, St. Martin's Press, New York, 1962.

Foss, C. F., *Armoured Fighting Vehicles of the World*, Charles Scribner's Sons, New York, 1971.

Gallagher, Matthew P., and Karl F. Spielmann, Jr., *Soviet Decisionmaking for Defense*, Praeger, New York, 1972.

"GAO, Urged by Senator Eagleton, Scrutinizes XM1 Program's Cost," *Army*, May 1975, p. 10.

Gooch, W. A., "Soviet Design Philosophy and Armor," *Armor*, September-October 1972, pp. 17-19.

Green, Constance M., Harvey C. Thomson, and Peter C. Roots, *The Ordnance Department: Planning Munitions for War*, Office of the Chief of Military History, Department of the Army, Washington, D.C., 1955.

Guderian, H., *Panzer Leader*, Ballantine Books, New York, 1957.

Harman, A. J., *A Methodology for Cost Factor Comparison and Prediction*, The Rand Corporation, RM-6269-ARPA, August 1970.

Hofmann, G. F., "A Yankee Inventor and the Military Establishment: The Christie Tank Controversy," *Military Affairs*, February 1975, pp. 12-18.

- Hofmann, G. F., "The Demise of the U.S. Tank Corps and Medium Tank Development Program," *Military Affairs*, February 1973, pp. 20-25.
- Holloway, D., *Technology and Political Decisions in Soviet Armaments Policy*, unpublished paper, University of Edinburgh, 1973.
- Hunnicut, R. P., *Pershing: A History of the Medium Tank T20 Series*, Feist Publications, Berkeley, Calif., 1971.
- Icks, R. J., *Light Tanks M22 Locust and M24 Chaffee*, AFV/Weapons Profile, Number 46, Profile Publications, Windsor, Berkshire, England.
- Icks, R. J., *M47 Patton*, AFV/Weapons Profile, Number 52, Profile Publications, Windsor, Berkshire, England.
- Icks, R. J., *The M48-M60 Series of Main Battle Tanks*, AFV/Weapons Profile, Number 24, Profile Publications, Windsor, Berkshire, England.
- Icks, R. J., *The M6 and M26 Pershing*, AFV/Weapons Profile, Number 32, Profile Publications, Windsor, Berkshire, England.
- Ireland, M. W., "MBT70/XM803," *Armor*, July-August 1970, pp. 33-34.
- Istoriia Velikoi Otechestvennoi Voiny Sovetskogo Soiuza, 1941-1945 (IVOVSS)*, (History of the Great Patriotic War of the Soviet Union), Voenizdat, Moscow, 1960-1965.
- Jones, R. E., G. H. Rarey, and R. J. Icks, *The Fighting Tanks Since 1916*, The National Service Publishing Co., Washington, D.C., 1933.
- Kehoe, J. W., Jr., "Warship Design: Ours and Theirs," *U.S. Naval Institute Proceedings*, August 1975, pp. 56-65.
- Khrushchev, N. S., *Khrushchev Remembers*, Little, Brown & Co., Boston, Mass., 1970.
- Klein, B. H., W. H. Meckling, and E. G. Mesthene, *Military Research and Development Policies*, The Rand Corporation, R-333-PR, December 1958.
- Kosyrev, E. A., et al., *Tanki (Tanks)*, DOSAAF Publishing House, Moscow, 1973.
- Krupchenko, I. E., et al., *Sovetskie Tankovye Voiska 1941-1945 (Soviet Tank Forces 1941-1945)*, Voenizdat, Moscow, 1973.
- Liddell Hart, B. H., *The Red Army*, Harcourt, Brace & Co., 1956.
- Marshall, S.L.A., "Armor East of Suez," *Armor*, November-December 1967, pp. 20-21.
- Matsulenko, V., "Massing of Forces," *Soviet Military Review*, No. 2, February 1975, pp. 54-56.

- Mayo, Lida, *The Ordnance Department: On Beachhead and Battlefield*, Office of the Chief of Military History, United States Army, Washington, D.C., 1968.
- McGwire, Michael, "Soviet Naval Procurement," in *The Soviet Union and Near East Seminar*, Royal United Services Institute, London, March 1970.
- Miller, R. A., "The United States Army During the 1930s," unpublished Ph.D. Dissertation, Princeton University, 1973.
- Milsom, J., *Russian Tanks, 1900-1970*, Stackpole Books, Harrisburg, Pa., 1971.
- Mostovenko, V. D., "History of the T-34 Tank," *Soviet Military Review*, No. 3, 1967.
- Mostovenko, V. D., "Soviet Heavy Tanks," *Soviet Military Review*, No. 2, 1968, pp. 48-49.
- Mostovenko, V. D., "Steps in Tank Building," *Tekhnika i Vooruzhenie*, No. 9, 1966. Translated by J.P.R.S. in J-1054, pp. 12-21.
- Mostovenko, V. D., *Tanki (Tanks)*, Voenizdat, Moscow, 1958.
- "NATO Completes Tank Gun Trials," *International Defense Review*, October 1975, p. 635.
- Nelson, J. R., and F. S. Timson, *Relating Technology to Acquisition Costs: Aircraft Turbine Engines*, The Rand Corporation, R-1288-PR, March 1974.
- Nelson, J. R., et al., *A Weapon-System Life Cycle Overview: The A-7D Experience*, The Rand Corporation, R-1452-PR, October 1974.
- Nelson, O., Jr., *National Security and the General Staff*, Infantry Journal Press, Washington, D.C., 1946.
- Nenninger, T. K., *The Development of American Armor, 1917-1940*, Masters Thesis, University of Wisconsin, 1968; portions published in *Armor*, January-February through September-October 1969.
- "New Russian Tanks on Winter Exercise," *International Defense Review*, April 1975, p. 487.
- "New Soviet Weapons Unveiled in Mideast," *Aviation Week & Space Technology*, March 24, 1975, pp. 14-17.
- "Notes: Battle Tanks," *Military Review*, January 1974.
- Ogorkiewicz, R. M., *Armor: A History of Mechanized Forces*, Praeger, New York, 1960.
- Ogorkiewicz, R. M., *Design and Development of Fighting Vehicles*, Doubleday & Co., Garden City, N.Y., 1968.

- Palmer, R. R., "Organization and Training of New Ground Combat Elements," in Kent Roberts Greenfield, Robert R. Palmer, and Bell I. Wiley, *The Organization of Ground Combat Troops*, Historical Division, Department of the Army, Washington, D.C., 1947.
- Pavlovsky, Ivan, "The Main Fire and Striking Power," *Soviet Military Review*, No. 2, February 1975, pp. 8-11.
- Perry, R. L., *A Dassault Dossier: Aircraft Acquisition in France*, The Rand Corporation, R-1148-PR, September 1973.
- Perry, R. L., et al., *System Acquisition Strategies*, The Rand Corporation, R-733-PR/ARPA, June 1971.
- Phillips, A., *Technology and Market Structure*, D.C. Heath and Company, Lexington, Mass, 1971.
- Pogue, F. C., *George C. Marshall: Education of a General*, The Viking Press, New York, 1963.
- Schreier, K. F., "The American Six-Ton Tank," *Armor*, November-December 1968, pp. 45-49.
- Schroeder, G., "The Economic Reform as a Spur to Technological Progress in the USSR," *Jahrbuch der Wirtschaft Ost Europa*, Vol. II, Munich, 1971.
- Sherwood, R. E., *Roosevelt and Hopkins: An Intimate History*, Harper & Row, New York, 1948.
- Shiovitz, N. H., "The T-95 Tank," *Armor*, January-February 1976, pp. 25-27.
- Sokolovskii, V. D., *Voennaia Strategia (Military Strategy)*, 2d ed., Voenizdat, Moscow, 1963.
- "Soviet Notebook," *International Defense Review*, June 1974, p. 708.
- "Soviets Continue Low-Key Export Effort," *Aviation Week & Space Technology*, May 29, 1967, pp. 157-165.
- Stoiko, Michael, *Soviet Rocketry: Past, Present, and Future*, Holt, Rinehart & Winston, New York, 1970.
- Sullivan, L., Jr., Assistant Secretary of Defense (PA&E), *Rationale for the Five Year Defense Topline Projection*, Testimony Before the House Committee on Armed Services, April 14, 1975.
- Sutton, A. C., *Western Technology and Soviet Economic Development, 1920 to 1945*, Hoover Institution Press, Stanford University, 1971.
- Thomson, H. C., and L. Mayo, *The Ordnance Department: Procurement and Supply*, Office of the Chief of Military History, Department of the Army, Washington, D.C., 1960.

"Two Decades of the 'Twenty-One'," *Air Enthusiast International*, May 1974, pp. 226-232.

U.S. Army Armor School, *Comparative Characteristics of Main Battle Tanks*, Fort Knox, Ky., 1973.

"U.S. Finds SA-6 To Be Simple, Effective," *Aviation Week & Space Technology*, December 3, 1973, p. 22.

U.S. Department of Commerce, *Historical Statistics of the United States*, Series E36-37, U.S. Government Printing Office, Washington, D.C., 1960.

United States Army Weapons Command, *Procurement History and Analysis of M60 Tank Family*, AMSWE-PPR-69-02, January 1969.

United States, House of Representatives, Committee on Appropriations, *DoD Appropriations Bill 1970*, Report No. 91-698.

United States, House of Representatives, Committee on Appropriations, *DoD Appropriations Bill 1972*, Report No. 92-666.

United States, House of Representatives, Committee on Armed Services, *Review of Army Tank Program*, 91st Cong., 1st Sess., July 9, 1969.

United States, Senate, Hearings Before the Committee on Armed Services, *Fiscal Year 1974 Authorization for Military Procurement, Research and Development, etc., Part 4, Research and Development*, 93d Cong., 1st Sess., April 1973.

United States, Senate, Committee on Armed Services, *Hearings on Military Posture and DoD Authorization for Fiscal Year 1975, Part 4*, 93d Cong., 2d Sess., March 1974.

Vannikov, B., "Iz zapisok Narkoma Vooruzheniia" ("From the Notes of the Commissar of Armaments"), *Voenno-istoricheskii zhurnal*, No. 2, 1962.

Vladimirov, L., *The Russian Space Bluff*, Tom Stacey Ltd., London, 1971.

Von Mellenthin, F. W., *Panzer Battles*, Ballantine Books, New York, 1971.

Weigley, R. F., *The American Way of War: A History of United States Military Strategy and Policy*, Macmillan Company, New York, 1973.

Williams, J., "Tank Analysis," *Armor*, March-April 1974, pp. 9-15.

Yakolev, A. S., *Targets of Life*, Clearinghouse, Department of Commerce, AD674316, translated from *Tsel' Zhizni*, Isdatel'stvo Politicheskoy Literatury, Moscow, 1966.

Yelshin, N., "Tanks versus Tanks," *Soviet Military Review*, No. 2, February 1975, pp. 28-30.